The TREND IN ENGINEERING

at the University of Washington

In this issue:

GRADUATE STUDIES AND RESEARCH IN ELECTRICAL ENGINEERING

LUNAR TIDAL VARIATIONS IN THE HEIGHT OF IONOSPHERIC LAYERS

LOGICAL PROCESSING AND CONTEXT ANALYSIS IN MECHANICAL TRANSLATION

RADIATION PATTERN SYNTHESIS WITH SOURCES LOCATED ON A CONICAL SURFACE

A BROADBAND DUAL-MODE TRANSDUCER

THE SOLUTION OF LARGE NETWORKS BY SECTIONALIZING

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THE NEW ENGINEER

A Guest Editorial

AUSTIN V. EASTMAN
Executive Officer, Department of Electrical Engineering

CHANGES HAVE TAKEN PLACE in engineering during the last fifteen to twenty years which have had profound effects on both the educational processes and the attitudes of employers towards young engineering graduates. Basically these changes have been of two kinds, (1) a great expansion of engineering knowledge to a point where engineering students cannot possibly learn the details of more than one or two fields of application during their four years of college, and (2) much greater use of pure science at a much higher level in engineering research and development so that more of a student's time in college must be devoted to science and analysis, and less to application and empiricism. The manner of meeting this situation is often summed up by the statement that "colleges must confine their teaching to fundamentals," but the definitions of what is meant by "fundamentals" are almost as many as there are educators. Some extremists consider the teaching of detailed techniques of design or analysis in specific fields (fields which the individual considers to be of maximum importance) to be fundamentals. More recent thinking today, however, considers the teaching of the basic sciences of mathematics, physics, and chemistry, together with general methods of engineering analysis and synthesis based on the pure sciences, as teaching fundamentals.

One of the interesting experiences which have strongly influenced modern thinking along engineering educational lines, is that of some of the electronic laboratories which were set up during the early days of World War II. The immediate need was to develop electronic gear to combat the submarine menace, as the Allied cause was losing ships faster than it could build new ones. Both physicists and engineers were employed by these laboratories and the general experience was that the physicists proved to be more effective in developing new circuits and especially new ideas and devices to meet this pressing need than the engineers. Why? Because too many of the engineers had been trained in specific techniques, not in basic thinking, analysis, and synthesis, whereas the physicists had been trained along the lines of intellectual curiosity, so that their thinking was much less bound by conventional practices than was that of the engineers. True, the physicists had to develop the ability to apply the results of their basic thinking and analysis in order to develop practical engineering gear, but this seemed to be a much easier process than for the engineers to acquire the ability to think along original, scientific lines. Obviously these conclusions did not apply to *all* engineers nor to *all* physicists, but the number to which they did apply was quite significant.

Just what does this mean with respect to engineering education? The conclusion which many far-seeing engineering educators have drawn, as evidenced by the changes made in curricula and methods of teaching, is that engineers must be taught more basic science, and encouraged to develop more intellectual curiosity and given training in more basic methods of analysis and synthesis. On the other hand, this does not necessarily mean that engineering students should take a lot less engineering and a lot more physics and mathematics, though some increase in mathematics and physics courses is certainly indicated, and it certainly does not mean that engineers should become physicists and mathematicians. It does mean that engineering courses themselves must be taught from a broader and more scientific point of view, in such a manner as to be applicable to as wide a variety of specific problems as possible, with the application to engineering problems exemplified by a reasonable number of well-chosen problems of as diverse a nature as is practicable, all worked out from the broad basis on which the student is taught.

Let us take the teaching of electric-circuit solutions as an example. The old and time-worn system was to teach students how to solve a simple series circuit, a simple parallel circuit, a simple combination of these, and so on into more and more complicated circuits. Too often the student was left with the impression that each circuit was a specific type of problem in itself and unless he could remember the method of attacking that specific type of circuit, he was unable to proceed with its solution. Instead, the student should be taught one or two basic general procedures (e.g., the mesh method, the nodal method) by means of which he can attack any circuit, no matter how complex, and then learn how to use these procedures by working out a sufficient variety of problems as to master the general approach. The generality of approach to circuit solution requires the introduction of the ideas of topology (trees, links, etc.), superposition and reciprocity.

The alert student, when applying these principles to relatively simple problems, will note that time can sometimes be saved by taking "short cuts," but if he is allowed to do so while laying his foundations in the fundamentals of analysis, he may lose some ability to cope with more complex problems later. Once he has laid his foundations, he will readily find and adopt suitable short cuts either in his senior and graduate work, or in actual engineering work after graduation.

Another way of directing the student's thinking toward the more basic concepts is always to give him the most general form of any given relationship that he is capable of handling, even though a simpler form may be adequate for solving the immediate problem at hand, and then show that this more general form can be reduced to the simpler form under certain specific conditions. This will avoid his use of simpler forms where they are not applicable and will enable him to concentrate on a single general relationship which may be used to solve all problems involving this particular principle.

As a very simple but fundamental example, consider the relationship between force, distance, and energy. Usually the student is first introduced to this relationship in the following form:

$$W = Fs,$$

where F is the force acting, s is the distance through which it acts, and W is the energy expended (or work done). The careful teacher will state that the force must act in the direction through which it moves and must be constant throughout this distance, but the student may either not fully recognize these limitations or may wonder what he should do under other conditions. In other words, he has taken the first step in building up a group of relationships

(Continued on page 34)

Electrical Engineering at the University of Washington

1898-1958

C. E. Magnusson
1897-1941

The Department of Electrical Engineering was officially established by the Regents in 1897. The basic courses in Physics, Chemistry, Mathematics, etc., had been given for several years but the technological courses listed in the catalogue as required for the proposed four-year curricula in the three departments of the College of Engineering were largely on paper.

The first member of the Faculty giving courses in Electrical Engineering was Theodore E. Doubt, Professor of Physics and Electrical Engineering, 1898-1902. From 1902-06 the Department of Electrical Engineering, in combination with the Department of Physics, was under the direction of Frederick A. Osborn, Professor of Physics and Electrical Engineering (1902-04).

In 1906 the Department of Electrical Engineering was separated from the Department of Physics, and Carl Edward Magnusson, Professor of Electrical Engineering, was appointed Head of the Department of Electrical Engineering, a title which he held until his death in 1941. In 1917 he assumed additional administrative responsibilities when he was also named dean of the College of Engineering (1917-1929), and became the first Director of the Engineering Experiment Station (1917-1941). Dr. Magnusson did much of the basic work on the studies for the Grand Coulee Dam, pointing out the importance to the state of Washington of building a high dam, and, when this idea was approved, making a study of a power grid system for economical transportation of power to the people of the Northwest. He was the author of several engineering text books and a large number of other publications.

The first laboratory used by the Electrical Engineering Department consisted of a small room, approximately 25 x 35 feet floor space, in the basement of Denny Hall. In 1909, the class rooms and laboratories were moved to Engineering Hall, where the Department remained during Dr. Magnusson's lifetime. By the end of his regime, the faculty staff had increased to eight.

From 1901-1941, 764 graduates from the four-year course received the B.S. degree. Graduate work in the Department led to the granting of the first M.S. degree in Electrical Engineering in 1915, and during the following 26 years, a total of 35 such degrees were granted.

Following Dr. Magnusson's death in 1941, Austin V. Eastman, a University of Washington alumnus (1922), who had been on the Department's teaching staff since 1924, was named chairman of the Department, a position he still holds. The size of the Department's student body remained nearly constant from 1937 until 1946 when the first flood of returning GI's appeared. The number of students increased to a maximum of about 480 (not including freshmen* in 1948) and then dropped back to a minimum of 230 in 1951. In 1952 this increased to 250, and since that time the student body has been increasing at a nearly constant rate of 70 students per year, with the enrollment in the fall of 1957 being 570. Of these, 104 were graduate students, including 13 Ph.D. candidates. A total of nearly 700 are expected in 1958-9, including 50 under the Navy Enlisted Advanced School Program. A total of 1285 B.S. degrees were granted 1941-1958 and 91 M.S. degrees. The first Ph.D. degree was awarded last June.

A. V. Eastman
1942-

To meet the requirements of this increased load, the faculty staff rose to 25 in 1948, dropping to 16 in 1950-51. Since that time a steady growth in the Department has made it necessary to add continually to the staff so that there will be a total of 34 in the autumn of 1958. Of these, ten will be full professors, five associate professors, eight assistant professors, and the rest instructors most of whom will be appointed on a temporary basis.

In 1948 the Department moved into the new Electrical Engineering Hall which has nearly three times the floor area formerly available to the Department. At the end of ten years in this building office space now is completely used up, classrooms are at a premium, and laboratories and research rooms are all filled nearly to capacity. It has become obvious that additional space must be provided within the next few years and plans are being laid for a new wing to Electrical Engineering Hall, to be constructed during the 1961-63 biennium.

Recent years have seen remarkable changes in emphasis in electrical engineering curricula. Some of these are indicated in the editorial appearing in this issue of *The Trend*. In particular, steps are being taken at the University of Washington toward selecting, at the end of the sophomore year, those students who show the greatest aptitude for scientific work as evidenced for the most part by their grades in mathematics and in their sophomore courses in Electrical Engineering. These students will be guided toward at least one year of graduate work and will be allowed to substitute a limited number of mathematics and physics courses for some of the more applied work normally required. A basic core of courses has been set up at the sophomore and junior levels which are taken by all Electrical Engineering majors. A group of senior electives has been developed by the faculty of the Department to permit a student to apply the basic training of the core courses in intensive analysis and synthesis of some specialized area which is of interest to him.

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* Since 1923 the Department of General Engineering has handled all freshman engineering students.

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CONTENTS

The New Engineer (guest editorial)
Austin V. Eastman 1

Electrical Engineering at the University of Washington: *1898-1958* 2

Graduate Studies and Research in Electrical Engineering 5

Lunar Tidal Variations in the Height of Ionospheric Layers *H. M. Swarm, D. Dobrott, R. Nagata* . . 8

Logical Processing and Context Analysis in Mechanical Translation
David L. Johnson, Robert E. Wall 14

Radiation Pattern Synthesis with Sources Located on a Conical Surface *A. Ishimaru, G. Held* . . . 23

A Broadband Dual-Mode Transducer
Arthur W. Guy, G. Held 27

The Solution of Large Networks by Sectionalizing
Laurel J. Lewis 31

Engineering Research Dividends 34

A Superheterodyne System for Cross-Modulation Measurements on Low-Power Traveling Wave Tubes *E. B. DeGroot*

A Study of Digitally Controlled Systems by Analog-Computer Simulation *J. L. Saugen*

Investigation of the Cut-Off Region for a Microwave Metal-Strip Artificial Dielectric *T. Y. Otoshi*

LEGEND

CLOCKWISE FROM UPPER LEFT

Professor Clark *(right)* shows his servomechanism equipment to Mr. Stacey of the University of British Columbia.

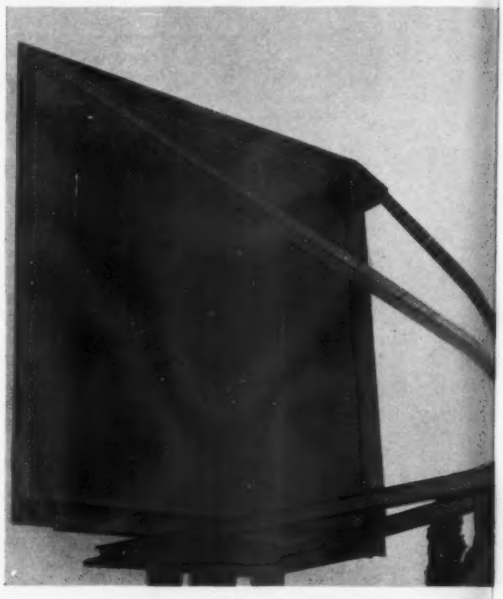
John Parente, graduate student, with the analog computer.

Part of a radial surface wave antenna designed for a flush-mounted omnidirectional aircraft antenna.

Gene Burns, graduate student, with polar recorder and associated amplifiers and the rotor control for antenna range.

Electrical Engineering Hall, opened for use in 1948.

Experimental electrode array used to guide migrant salmon past dams or other water-usage projects that might endanger them. *(See page 6.)*



Graduate Studies and Research in Electrical Engineering

1956-1958

THE DEPARTMENT OF ELECTRICAL ENGINEERING since its last report in October, 1955, has continued to widen the scope of its research activities as well as to develop many of the projects already under way at that time. The following outline presents the projects conducted by the faculty staff or under their direct supervision.

F. R. BERGSETH
Professor of Electrical Engineering

PROJECT: Study of power transmission line relaying problems

SPONSOR: Bonneville Power Administration

This project, which has been a continuing one for the past six years, is at present devoted to two principal subareas of activity:

1) Studies of the use of modern electronic devices such as transistors and other solid-state devices for power system relaying and control applications. A prototype transistorized distance relay is now installed in a BPA substation to provide service experience. A transistorized automatic oscillograph start relay will shortly be placed in service.

2) Mathematical studies of improved relay connection systems for distance relaying are in progress, as is a study of carrier current transfer trip relaying during the time of a fault on the line serving as a carrier channel.

R. N. CLARK
Assistant Professor of Electrical Engineering

PROJECT: The dynamic problems associated with the automatic control of unstable mechanisms.

A preliminary paper on this subject, based on work done by the author while he was with the Minneapolis-Honeywell Company, was presented to the Seattle Section of the AIEE in December, 1957. It reported as follows:

> A quasi-linear analysis of a servomechanism with an unstable internal feedback loop was made. This analysis showed that such a system may have a negative velocity constant, and that it is always conditionally stable. The practical implications of these two properties were discussed.

Application for sponsorship has been made to the National Science Foundation for support of a project aimed at extending the work reported in this paper. The extended work would treat the problem of controlling an unstable mechanism which is nonlinear.

PROJECT: To study the performance limitations of a feedback servomechanism system when it is conditionally stable, and to devise means for minimizing or eliminating these limitations.

SPONSOR: Engineering Experiment Station

A bibliography was compiled of literature which concerns conditionally stable feedback systems. A laboratory servomechanism demonstrator was assembled for experimental investigations in this area. It has facilities for varying the position and velocity loop gains and for changing load conditions over a wide range of inertia and elastic restraint values.

PROJECT: Control of fighter-type aircraft to minimize the inertia coupling which is present during rolling maneuvers.

A linearized analysis of the problem, made by Louis Miovski, graduate student, has resulted in a criterion for design of the feedback signals to be used in an automatic pilot. The criterion so derived is being checked by an analog computer simulation of the nonlinear problem.

A. E. HARRISON
Professor of Electrical Engineering

PROJECT: Investigation of the intermodulation properties of traveling-wave tube amplifiers at microwave frequencies.

SPONSOR: National Science Foundation

The experimental discovery of unexpected negative values of cross modulation at low levels, indicated by an increase in signal strength of a desired signal when a weak interfering signal is introduced, has focused attention on the need for additional analytical work on this problem. Experimental equipment is being improved so that additional tests can be made to determine the best approach toward an analysis.

PROJECT: Photogrammetric Survey of Coleman-Roosevelt Glacier, Mt. Baker, Washington.

SPONSOR: National Science Foundation

A growth of 110 million cubic feet of ice and snow at the Coleman-Roosevelt Glacier was measured for the period October 6, 1956, to September 20, 1957. This growth was surprisingly large when the light snowfall and warm spring of the 1957 season are considered. Plans to improve the accuracy of the survey and install an additional baseline for measuring the Coleman tongue, now hidden behind trees, could not be completed because of poor weather and limited manpower.

G. HELD

Associate Professor of Electrical Engineering

DEVELOPMENT OF A LABORATORY

During the past few years a well-equipped Microwave Laboratory has been developed by the combined efforts of the following organizations: the Department of Electrical Engineering, the Engineering Experiment Station, and to a certain degree, help from research contracts with the Boeing Airplane Company and the U. S. Air Force. This Laboratory is now equipped to do all kinds of microwave radiation and propagation problems.

The nature of the projects that were undertaken in this Laboratory can be listed in general in the following classes:

1) Radiation from sources on conical surfaces
2) Synthesis of source arrays on conical surfaces
3) Effects of unisotropic materials, like ferrites, on propagation and radiation
4) Multimode control and excitation
5) Flush mounted antennas
6) Broadbanding of radome walls

PROJECT: Conical Antenna Study

SPONSOR: Air Force Cambridge Research Center

This study is concerned with the radiation from slot arrays on conical surfaces. One of its prime aspects has been the interactions of the tip of the cone with an array placed on its surface. Theoretical and experimental research is being conducted on these problems. A related, but more complex, problem has undergone considerable theoretical study. This is the problem of synthesizing the slot arrays on a conical surface required to generate a desired radiation pattern.

PROJECT: Cavity Mode Studies

SPONSOR: Boeing Airplane Company, Physical Research Staff, Seattle, Washington

This study involved investigation of the excitation and independent control of a number of modes in a cavity or waveguide. These modes were designed to control the illumination of an aperture and consequently the radiation pattern.

PROJECT: Radome Studies

SPONSOR: Boeing Airplane Company, Physical Research Staff, Seattle, Washington

This study is concerned with the problem of broadbanding radome walls. Its purpose is to design a radome that will operate effectively over bandwidths considerably larger than presently available structures. Along with this problem, periodic loading of waveguides and the associated artifical unisotropic structures that they can present, have also been studied.

PROJECT: Flush-Mounted Antennas

SPONSOR: Boeing Airplane Company

This study is concerned with the problem of designing a broadband flush-mounted antenna that will be unidirectional and horizontally polarized. This problem led to an extensive study of radiating radial surface waves. Such structures were achieved by the use of space modulated circular slots or rings.

OTHER PROJECTS:

Aside from the above sponsored projects, the Laboratory has also been engaged in research work that was either supported by the Engineering Experiment Station or by the Boeing Airplane Company in the form of supporting the work at the Boeing plant. These projects involved: (1) A study of the radiation from ferrite loaded waveguides; (2) a study of artificial unisotropic dielectrics for the use in generation of circularly polarized waves; (3) a study of spiral antennas that are of dimensions comparable to or longer than the wavelength; (4) a study of the excitation and resonant frequencies of conically shaped resonant cavities; (5) a study of radiation through unisotropic materials and the effect of such unisotropies on the bore sight error caused by a radome around an antenna.

Since the 1955 report, nine Master's theses have been written by the students working under Dr. Held's supervision. One Ph.D. dissertation is just being completed.

G. L. HOARD, *Professor of Electrical Engineering*

in cooperation with

LEON A. VERHOUVEN

Research Professor of Fisheries

PROJECT: Effects of Electricity on Salmon.

SPONSOR: U. S. Army Corps of Engineers

This project, part of an over-all program to develop means of safely by-passing migrant fish around power dams, was divided into two investigations.

1) An experimental investigation of the harmful effects, both immediate and latent, of electricity on salmon and steelhead trout.

2) An experimental investigation of electroguiding of migrant fish.

The first portion of the contract period was spent in a laboratory investigation of the lethal or other harmful effects of electricity on salmon and steelhead trout. Approximately the last year of the contract period was devoted to an attempt to guide migrant fish by means of the attractive (electrotaxis) effect of electricity. A field installation was made on the White River diversion flume located near Buckley, Washington, belonging to the Puget Sound Power and Light Company. The final report of findings is now in the process of preparation.

DAVID L. JOHNSON
Associate Professor of Electrical Engineering

PROJECT: Study of Hydro-Storage Problems

SPONSOR: Engineering Experiment Station (228)

RESEARCH ASSISTANT: P. R. Menon

An evaluatory study is being made of methods of optimizing hydro usage in large multireservoir hydroelectric systems. The sponsorship of the Engineering Experiment Station has now expired, but the project is continuing and will be extended this summer under the sponsorship of the International Business Machines Corporation.

PROJECT: Language Translation

SPONSOR: Engineering Experiment Station (157)

RESEARCH ASSISTANT: A. D. Stathacopoulos

This project continued work regarding the block analysis of sentences as applied to digital computers. The purpose of the propect was to extend the scope of the study to the Russian language.

PROJECT: Mechanical Translation.

SPONSOR: United States Air Force

ASSISTANTS: R. E. Wall, U. K. Neihaus, A. D. Stathacopoulos.

This is a continuing, large-scale project being carried on jointly by the Department of Far Eastern Languages and the Electrical Engineering Department. The goal is the development of the means, both physical and theoretical, to provide an accurate, intelligible translation of Russian technical literature into the English language.

LAUREL J. LEWIS
Professor of Electrical Engineering

PROJECT: Application of Digital Computers to Electric Utility Problems

SPONSOR: City of Seattle, Department of Lighting

ASSISTANT: Balraj G. Sokkappa, Instructor in Electrical Engineering

Studies involving the use of computers, including the preparation of programs for the IBM 650, have been made in two major areas:

a) Calculations of power flow in large electrical networks

b) Scheduling of hydro generation for optimum utilization of reservoir storage.

The network studies have been concerned with procedures for obtaining network equivalents, and techniques for accelerating the convergence of iterative calculations.

Programs have been prepared for calculating optimum reservoir regulation and generation for the plants on the Skagit River, in coordination with load requirements and power interchange between the Seattle, Tacoma, and Bonneville Power Administration systems. Case studies have been processed, with load estimates through the year 1966, to note the effect of alternate additions to generating facilities in relation to needs for purchase of supplementary power.

FLOYD D. ROBBINS
Associate Professor of Electrical Engineering

PROJECT: Engineering analysis of the Mayfield Hydroelectric Development, Cowlitz River.

SPONSOR: State of Washington, Department of Fisheries, Research Division.

A study and analysis was made of the engineering and economic feasibility of this project.

PROJECT: Engineering study of the use of modern steam power plants using Washington coal as fuel.

SPONSOR: State of Washington

As a result of publication in *The Trend in Engineering* of two articles, the author was asked to report on this subject to the 1957 session of the Washington State Legislature, which then appropriated $257,000 for further study of the problem.

PROJECT: Engineering analysis of the Mayfield-Mossyrock Hydroelectric Project and of a substitute thermal power plant.

SPONSOR: State of Washington Department of Fisheries, Research Division.

A comprehensive study was made of the economic feasibility of the development of the Cowlitz River by the City of Tacoma. The report also included a design and study of a coal-fired plant as a possible substitute for the hydroelectric development which would destroy the salmon runs and spawning grounds.

PROJECT: Engineering study of the hydroelectric possibilities of the Wynooche Basin.

SPONSOR: State of Washington Department of Fisheries, Stream Development Division.

PROJECT: Engineering study of the hydroelectric possibilities of the Skokomish.

SPONSOR: State of Washington Department of Fisheries, Stream Development Division.

The objective here was to find possible alternate projects which would not be destructive to fish runs.

PROJECT: Water use study of the Columbia and Snake Rivers, with particular reference to the Nez Perce project.

SPONSOR: State of Washington Department of Fisheries, Research Division.

The purpose of this project was to study hydroelectric sites in the Columbia River basin and to recomend those feasible projects which would not be destructive to anadromous fish.

(Continued on page 35)

LUNAR TIDAL VARIATIONS IN THE HEIGHT OF IONOSPHERIC LAYERS

H. M. SWARM
Associate Professor of Electrical Engineering

D. DOBROTT AND R. NAGATA
Seniors in Electrical Engineering

H. M. Swarm

Introduction

Tidal phenomena in the ionosphere are of importance in determining the over-all radio propagation anomalies of many of our practical communication systems. Two important tidal effects are present in the ionosphere: (1) the effect of the sun and (2) the effect of the moon. The solar effect on critical frequencies of the various ionospheric layers has been apparent for many years. The lunar effects have been much less obvious but nonetheless have been known to exist for some time. Many of the lunar tidal studies have been concerned with the critical frequencies of the F layer and a few workers[1,2,3-7] have investigated the height tidal effects of both the E and F layers. Tidal phenomena in the ionosphere are complicated by the compressibility of the gases, and hence a simple extension of the ocean tidal theory is not adequate. Much of the presently accepted magnetic theory of ionospheric tidal phenomena is due to Martyn[2,3,8] and Pekersis.[9] As a consequence of the development of the theory, the expected variation in height and time of maximum amplitude of the ionospheric lunar tides are not constant with local time but are dependent upon the geomagnetic latitude. Much of the past work has been done at widely separate geomagnetic latitudes, but at various times and without systematic study of the over-all effect. In fact, some tidal effects repeated at the same location[10,11,12] a few years later show opposite phase relationships and considerable change in amplitudes.

This paper is a preliminary report on a several-year research effort that intends to investigate the simultaneous lunar tidal effects in a number of locations and to establish the basic tidal behavior on a world-wide basis. The results of such an effort should clearly establish the zonal distribution of the tidal phenomena and substantiate or disprove the predicted phase reversal of the E region height variation. This paper also shows the lunar tidal height variations of the sporadic-E layer of the ionosphere over Stanford, California, obtained by one of the authors a few years ago.

D. Dobrott

The heights of the sporadic-E-layer reflections, according to Gallet's theory,[13] are believed to be intimately related to the normal E layer. Since a lunar tidal variation in the E-layer reflection height has already been established by Appleton and Weeks,[1] a tidal effect should be present in the sporadic-E layer as a consequence of Gallet's theory. Helliwell[14] has noted certain preferred heights of reflections of the sporadic-E layer which appear to be related to other phenomena associated with the E region. These heights are approximately 100, 106, and 112 kilometers, and are almost the same as the preferred optical height of the aurora as noted by Egedal.[15] Egedal also noted that the optical height of the aurora reflections were higher at lunar flood tide than at lunar ebb tide, and thus inferred a lunar tidal effect.

The following sections describe instrumentation equipment, the lunar time calculation, the tidal analysis, and the comparison of the tidal variations with the work of other, previous investigations.

Ionospheric Recorder

The ionospheric height data for the tidal analysis are obtained from an automatic recorder. This recorder sends a pulse of RF energy vertically upward to the ionosphere where it is reflected and returned to the receiver. The time delay between the transmitted and received pulses reflected by the ionosphere gives a measure of the virtual height. The virtual height so recorded as a function of frequency, is defined as the product of the delayed time of the echo and one-half the

R. Nagata

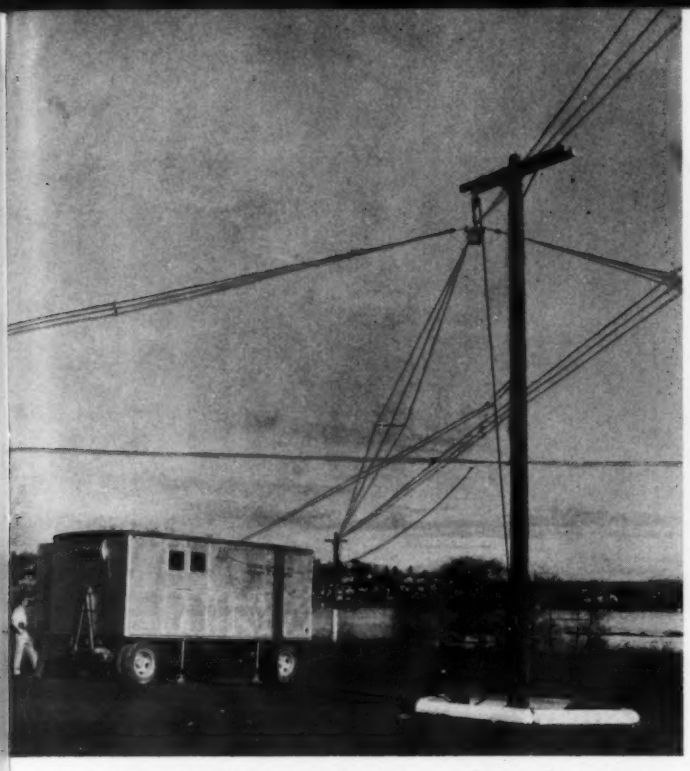


FIG. 1. IONOSPHERE RECORDER TRAILER AND DELTA ANTENNAS

velocity of light.

Automatic vertical incidence recorders have been developed by the National Bureau of Standards and are at present operating throughout the world. These instruments perform a key function in the ionospheric research program of the International Geophysical Year.

The carrier frequency is controlled by a single variable frequency oscillator that synchronizes both the transmitter and receiver. The frequency range is continuously variable from 1 to 25 megacyles and the peak pulse power output is approximately 10 kilowatts. The transmitted pulses are approximately 50 microseconds in length with a repetition frequency of approximately 30 pulses per second. The recorder is constructed for complete automatic operation in which the 1-to-25 megacycle sweep is completed in 15 seconds. Records are normally taken every 15 minutes.

The transmitter and receiver are both connected to individual delta antennas which are at 90 degrees with respect to each other. The antenna configuration is such as to give essentially a vertical oriented antenna pattern at all frequencies. The over-all installation of this equipment is shown in Fig 1. The equipment is mounted inside the trailer and the center pole of the crossed delta antennas is visible on the right. A view of the front of the recorder from inside the trailer is shown in Fig. 2.

The output pulses from the receiver are presented on an oscilloscope to which is mounted a 35-mm movie-type camera for recording the data. A normal sweep frequency ionogram consists of a linear plot of virtual height versus a logarithmic frequency sweep. An example of a typical ionogram recorded with the automatic recorder at the University of Washington is shown in Fig. 3.

Lunar Time Calculations

The time of measurement of all data must be converted into lunar time. Since the best approximation of the moon's movements is calculated from Brown's equation which consists of about two thousand terms, it is more practical to use daily ephemeris values and interpolate. Lunar time is defined in the same way as local solar time; however, it is not desirable to use a "mean" time since the lunar variations from the mean are so extensive.

The start of the lunar day is based on lower transit of the moon with the upper transit representing twelve noon. Since the local hour angle is based on upper transit, the local lunar time is

$$T_\mu = LHA_\mu + 12^h, \qquad (1)$$

where T_μ is local lunar time, LHA_μ is the local hour angle.

Now the hour angle of any celestial object is equal to the sidereal time minus the right ascension of that object. Applying this to the moon and also writing the local sidereal time in terms of the right ascension of the sun, we find, after considerable manipulation, that the local lunar time is equal to the right ascension of the sun minus the right ascension of the moon plus the local standard time as

FIG. 2. IONOSPHERE RECORDER C-2 MOUNTED IN TRAILER

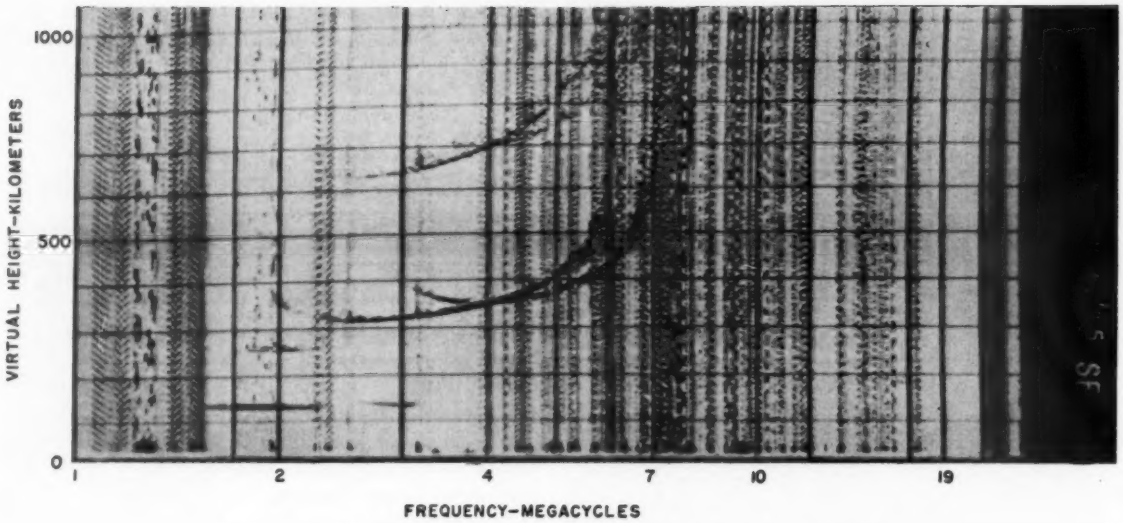


FIG. 3. IONOGRAM SHOWING SPORADIC E- AND F-LAYER REFLECTIONS

$$T_\mu = RA_s - RA_\mu + LST. \qquad (2)$$

This is the basic equation to be programmed on the IBM-650 electronic computer. The right ascension of the sun is relatively easy to compute, since in one mean solar day the right ascension increases 3.9426 minutes. Since the basis for determining any right ascension is the earth's vernal equinox, we must find for any particular datum the number of days since the vernal equinox of that year. Now the vernal equinox occurs on

March 23.00 for years $1950+4n$,
March 23.25 for years $1951+4n$,
March 23.50 for years $1952+4n$,
March 23.75 for years $1953+4n$,

where n is any integer. For programming purposes, the number of days after March 23 to the first of each calendar month is stored in the computer, and the days M since the vernal equinox to the first of the month is then found from

$$M = (\text{whole days since vernal equinox}) - 0.25\,[\text{Datum Year} - (1950+4n) + m], \qquad (3)$$

where m is an integer 0, 1, 2 or 3.
The total number of days N since the vernal equinox to a particular datum time is

$$N = M + d + LC + LST_d, \qquad (4)$$

where M is the number of days from the vernal equinox to the first day of the data month, d is the day of the month, LC is the longitude correction for changing local mean time to standard time, and LST_d is local standard time expressed in fraction of days. Thus the right ascension of the sun is found from multiplying the change in right ascension, in days, by N,

$$RA_s = \left(\frac{3.9426}{1440}\right) N = 0.00273792\, N. \qquad (5)$$

The right ascension of the moon, on the other hand, is much more difficult to obtain. Since the daily change of right ascension varies from about forty to about sixty-five seconds, it is necessary to devise an interpolation system to obviate storing the entire ephemeris. The general procedure is to store only the necessary ascensions for the days in which the data are obtained. The right ascension of the moon for 0 hour universal time is stored as Y_d for hours, Z_d for minutes, and ΔRA for the change in right ascension in minutes per day. Thus three entries are necessary for each day, and since most analyses are made on a lunar month the total number of stored constants is usually less than 100. Hence, the right ascension of the moon is obtained from the right ascension for 0 hour universal time of the datum day plus the fractional day after zero hour universal time multiplied by the change in right ascension per day.

$$RA_\mu = RA_{\mu 0} + RA_d \text{ (fractional datum day)}$$

$$= \frac{Y_d}{24} + \frac{Z_d}{1440} + \Delta RA_d\,(LC + LST_d). \qquad (6)$$

Thus the procedure is to insert the appropriate standard time of the data into the computing machine, where the right ascension of sun is computed, the right ascension of the moon is interpolated from the small stored table and subtracted from the sun's right ascension, and the standard time in days is added to this difference to obtain the lunar time in days and fractions thereof, as stated in Eq. 2.

Method of Analysis

The ionospheric height data are processed by a method contributed by Chapman and Bartels.[16] The method is briefly described as follows: A half lunar month of data is used in order to remove the solar height effect by including all possible phase relations of the moon with respect to the sun. The average of the heights during this half lunar month period is found for each of the solar time intervals. This average height usually rises during the day, with the maximum occurring just before midday and a small minimum about an hour after sunset, usually followed by a smaller maximum in the evening around 21:00 local solar time.

The lunar variation in height is noted by first taking the differences of each individual height measurement from the fourteen-day average value for that particular solar time and then tabulating all such differences in accordance with the corresponding lunar time as calculated by the method described in the previous section. The individual height differences that occur in a particular lunar time group are then averaged and these average values are subjected to a Fourier analysis to determine the semidiurnal sinusoid with the least-square error.

The calculation of a semidiurnal sinusoid with the least-square error follows from Vol. II of Chapman and Bartels.[16] Let the value of the function corresponding to a time t_i, whose range is $0<t<2\pi$ be

$$Y_0, Y_1, Y_2, \ldots Y_n .$$

If the data are obtained at 15-minute intervals there will be 96 Y_i ordinate values. Let the desired best fitting sinusoid be represented as a Fourier series.

$$y(t)=\frac{a_0}{2}+a_1\cos t+b_1\sin t+\ldots .+a_k\cos kt + b_k\sin kt, \qquad (7)$$

with $(2k+1)\leq n$.

For a semidiurnal sinusoid, only the $k=2$ terms are required, and y_k becomes

$$y_2=a_2\cos 2t_i+b_2\sin 2t_i . \qquad (8)$$

The best least-square fit of a sinusoid is obtained when summation of the square of the difference in ordinates is a minimum. Thus, let μ^2 represent this summation of squares as follows for $n=96$:

$$\mu^2=\sum_{i=1}^{i=96}[Y_i-y_2(t_i)]^2 . \qquad (9)$$

For a minimum μ^2,

$$a_k=\frac{2}{n}\sum_{-1}^{n}Y_i\cos kt_i , \qquad (10)$$

and

$$b_k=\frac{2}{n}\sum_{i=1}^{i=n}Y_i\sin kt_i . \qquad (11)$$

These for the $k=2$ and $n=96$ case become

$$a_2=\frac{1}{48}\sum_{1}^{96}Y_i\cos 2t_i ; \qquad (12)$$

$$b_2=\frac{1}{48}\sum_{1}^{96}Y_i\sin 2t . \qquad (13)$$

The amplitude of the best fitting sinusoid is

$$c_2=\sqrt{a_2^2+b_2^2} , \qquad (14)$$

with phase angle θ such that

$$\theta=\tan^{-1}\frac{b}{a} \qquad (15)$$

for

$$y_2(t_i)=C_2\cos(\theta+2t_i) . \qquad (16)$$

The time of maximum amplitude becomes

$$t_{max}=\frac{\pi-\theta}{2} . \qquad (17)$$

The correlation between the experimental data and the best fitting sinusoid may be expressed by the correlation coefficient r as

$$r=\frac{\sum y_2(t_i)Y_i-\dfrac{\sum y_2(t_i)\sum Y_i}{n}}{\left\{\sum[y_2(t_i)]^2-\dfrac{[\sum y_2(t_i)]^2}{n}\right\}^{\frac{1}{2}}\left[\sum y_i^2-\dfrac{(\sum Y_i)^2}{n}\right]^{\frac{1}{2}}} , \qquad (18)$$

and, by trigonometric identities, and since $\sum[y_2(t_i)]^2 = n/2$ and $\sum y_2(t_i)=0$, the correlation coefficient becomes

$$r=\frac{48(\sin\theta\, a_2+\cos\theta\, b_2-0)}{\left(\dfrac{96}{2}\right)^{\frac{1}{2}}\left[\sum Y_i^2-\dfrac{(\sum Y_i)^2}{n}\right]^{\frac{1}{2}}} = \frac{\sqrt{2}\;48c_2^2}{[96\sum Y_i^2-(\sum Y_i)^2]^{\frac{1}{2}}} . \qquad (19)$$

Let σ_s^2 be the variance of the data about the best fitting sinusoid. The variance is

$$\sigma_s^2=\frac{1}{96}\sum[Y_i-Y_2(t_i)]^2 . \qquad (20)$$

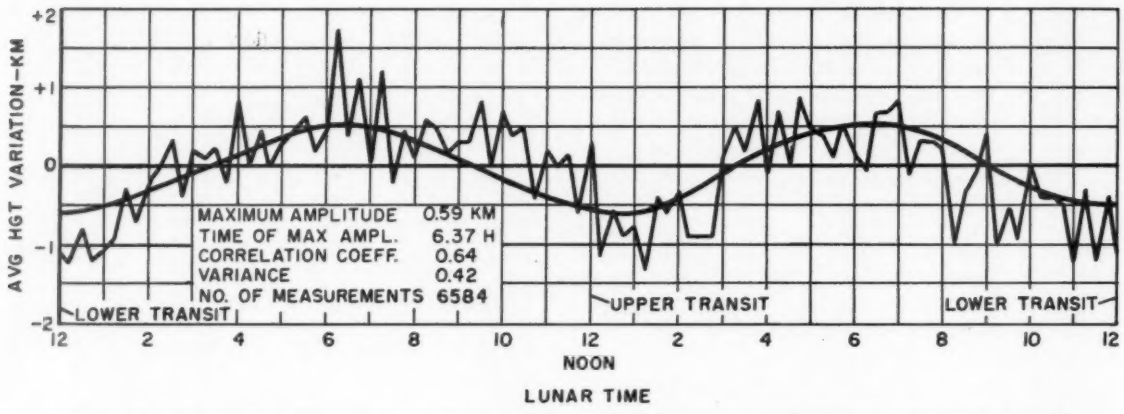


FIG. 4. LUNAR DIURNAL HEIGHT VARIATION OF LOWEST SPORADIC-E LAYER DURING SIX MONTHS OF 1951

The amplitude of the tide is found from Eq. 14 and the lunar time of maximum amplitude from Eq. 17. These equations, the correlation coefficient, and the variance have been programmed on the IBM-650 computer.

Experimental Results

A typical example of the results of this method of lunar tidal analysis is that obtained from ionograms taken at Stanford, California, during the period July 5 through December 28, 1951. In this study sporadic-E reflection traces appearing on the regular ionograms were accurately scaled on a special enlarger to an accuracy of plus or minus 1 kilometer. From these data the lowest level of reflection that showed continuity on several successive ionograms was used in the lunar tidal analysis. During July and through September, records were obtained at half-hour intervals and thereafter at quarter-hour intervals. The time of each measurement was preserved so that a maximum number of ordinates would be available for the Fourier analysis. Only heights between 90 and 125 kilometers were included, and the frequency at which the height measurements were made centered around 2.4 megacycles. Sometimes a frequency as low as 2.0 megacycles was used, and often during the daytime it was necessary, because of absorption, to use frequencies as high as 3.2 megacycles.

The amplitude of the semidiurnal tide and the phase were found from the analysis described in the preceding section. These results are shown in Fig. 4, together with the number of observations, the variance, and correlation coefficient of the experimental data with the best fitting sinusoid. The sinusoid best fitting the experimental data has an amplitude of 0.59 kilometers with a maximum amplitude

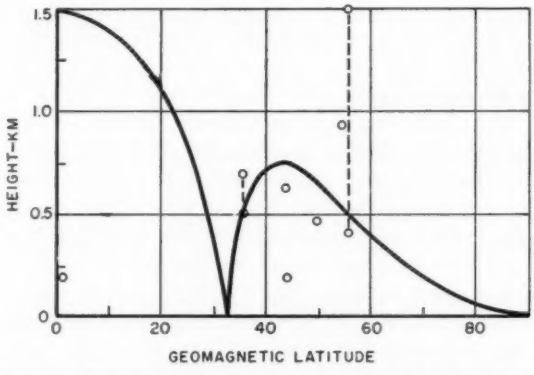


FIG. 5. MAXIMUM AMPLITUDE OF SPORADIC-E SEMIDIURNAL LUNAR TIDE VS GEOMAGNETIC LATITUDE

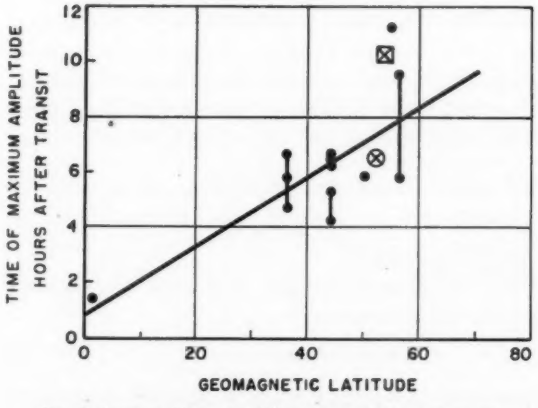


FIG. 6. LUNAR TIME OF MAXIMUM AMPLITUDE VS GEOMAGNETIC LATITUDE

TABLE I

LUNAR SEMIDIURNAL HEIGHT VARIATIONS IN THE E-REGION

LOCATION	GEOMAGNETIC LAT. & LONG.	RESEARCHER	LAYER	DATE OF DATA	MONTHS OF DATA	AMPLITUDE (km)	TIME OF MAX. AMPL. (hr.)
Slough	55° N - 84° E	Appleton & Weekes	E	Aug. 37-July 38	11	0.93	11.2
Canberra	44° S - 224° E	Martyn	E	1941-1944		0.19	5.1
Canberra	44° S - 224° E	Martyn	E	1941-49			4.1
Brisbane	36° S - 227° E	Martyn	E & E_s	June 43 - Dec. 47		0.5	4.5
Brisbane	36° S - 227° E	Matsushita	E_s	May 51 - April 52	13	0.70	5.7
Brisbane	36° S - 227° E	Thomas & Swenson	E_s	Dec. 52 - Nov. 53	10	0.69	6.7
Washington	50° N - 351° E	Matsushita	E_s	1949-1950	13	0.46	5.8
Huancayo	1° S - 354° E	Matsushita	E_s	1951-1952	13	0.19	1.3
Ottawa	56° N - 351° E	Littlewood & Chapman	E	Oct. 52 - Dec. 52		1.46	5.7
Ottawa	56° N - 351° E	Datars	E	May 54 - Sept. 54		0.40	9.5
Ottawa	56° N - 351° E	Jelly	E	Sept. 54 - Sept. 55	12	0.50	0.5-5.9
Ottawa	56° N - 351° E	Hogg	E	5 June 56 - 22 June 56		0.45	10.7
Ottawa	56° N - 351° E	Hogg	E	8 Aug. 56 - 22 Aug. 56		0.59	4.5
Stanford	44° N - 298° E	Swarm & Helliwell	E	July 51 - Dec. 51	6	0.59	6.4

occurring at 6.37 hours after lunar transit. These data have a correlation coefficient of 0.66 with a variance of 0.42. The average variation in height for all the experimental data is shown in Fig. 4 as the curve with discontinuous slope. The best fitting sinusoidal curve is the heavy continuous curve.

According to the theoretical work of Martin and Pekersis, we can expect the amplitude of the lunar tides to be dependent upon the geomagnetic magnitude. A plot of the relative theoretical amplitude of the total vertical drift of the ions in kilometers versus the geomagnetic latitude is therefore shown in Fig. 5. A summary of the results of previous workers is shown in Table 1. This table shows the lunar tidal observations in the E region of the ionosphere and includes the location of the geomagnetic latitude, name of researcher, normal or sporadic E layer observed, dates of observations, the resulting amplitudes, and local lunar time of maximum amplitudes. The table includes the results of this study. This general summary of the results of all researchers indicates that the amplitudes of all normal-E and sporadic-E semidiurnal lunar tidal height variations are between 0.19 and 1.5 kilometers. These data have been plotted with respect to their geomagnetic latitude in Fig. 5. It appears that the amplitudes at Huancayo (latitude 1°) and Canberra (latitude 44°) are much too small to fit the present tidal theory. At the other extreme, the amplitude at Ottawa (latitude 56°), reported by Littlewood and Chapman, and the amplitude at Slough (latitude 55°) are quite high. The rest of the data show a trend similar to that derived from the theory. However, the present data are much too meager to lead to any definite conclusions. It is quite apparent that more data are needed at high latitudes above 60 degrees and at low latitudes below 30 degrees.

The time of maximum amplitude has also been plotted with respect to the geomagnetic latitude in Fig. 6. Most of these data have a time of maximum amplitude approximately 6 hours after transit. The data at Slough (latitude 55°) and Ottawa (latitude 56°), reported by Datars, and one case reported by Hogg appear much higher than all the others, while the data at Huancayo (latitude 1°) is again much lower. The solid line in this figure is not a theoretical curve but merely an attempt to show the experimental trend of all data. Martyn's tidal theory predicts a phase reversal for the low latitudes (below approximately 35°) compared to the high latitude. If one accepts the time of maximum amplitude at Huancayo as nearly correct, it is apparent that the data of other locations with the exceptions of Slough and Ottawa (Datars and Hogg) have the predicted phase reversal.

The points in Fig. 6 marked with a cross denote the time of the maximum amplitude of a semidiurnal lunar tidal variation in absorption of E-layer echoes. The cross circumscribed with a circle represents the data obtained by Mitra[17] at Pennsylvania State University on 150 kilocycles. The cross within the square represents the data obtained by Appleton and Beynon[18] at Slough on 4 megacycles. The data of Mitra correspond closely with the phase of the sporadic-E height variations found at similar latitudes. Likewise the data of Appleton and Beynon correspond with the phase of the sporadic-E height variations found earlier by Appleton and Weekes.

This preliminary work has opened a whole area of important basic research concerned with the height studies of ionospheric layers. Further work is planned to analyze data taken during the same period from different latitudes so that the world-wide tidal theory may be confirmed.

(Continued on page 33)

LOGICAL PROCESSING AND CONTEXT ANALYSIS IN MECHANICAL TRANSLATION

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The application of digital computers to the mechanical translation of languages is currently receiving worldwide attention. Projects are in operation at five or six major universities and research centers in the United States; others, in England, Italy, and Russia. Of particular interest to military intelligence, the problem is emphasized by the increase in communication speed relating one lingual group to another and by the mass of significant material flowing through the channels of communication. The speed of translation, the economy of the process, and the lack of sufficient skilled translators familiar with highly technical specialization areas are all factors pointing toward the importance of automatizing the translation process.

As in many computer application problems, the most difficult and frustrating element of machine translation is the definition of the means of approach and the structure of the problem itself. In resolving this aspect of the solution, skilled linguists must necessarily play an extremely important part. Language is formed by usage, organically developing a complex hierarchy of rules. Although the rules are inviolate, they are extremely difficult to specify and bring to conscious realization. At the University of Washington, the Mechanical Translation (MT) Project has progressed by means of closely coordinated efforts between the linguistic and engineering members of the staff. The work, in many respects, has followed the familiar research and development pattern; theoretical development has been followed to a certain point, the method is automatized and tested, then analysis of results yields further advances upon the theory.

The mechanical translation problem can be easily stated. It is necessary that a high-speed means be found to provide accurate and intelligible translation from one language to another. The MT Project at the University of Washington deals with translation of general technical literature from Russian to English. The problem can be grossly divided into two parts. A computer memory or dictionary must be available for use in the translation process. The dictionary output must then be logically processed to provide a clear output translation.

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The requirement of a dictionary or lexicon is obvious. The need for logical processing of the dictionary output is evident when the form of a normal dictionary output is considered. In human usage of a bilingual dictionary a single input word in the source language almost invariably yields multiple output words in the target language. Combining the effects of the multiple target alternatives and other grammatical problems, the raw dictionary output is one that may be accurate; but the intelligibility is subject to considerable interpretation.

Dictionary Storage

Most groups working with the mechanical translation problem are approaching the computer application from the standpoint of using available general purpose digital computers with their associated storage facilities as the translation dictionary. While this may be acceptable from the criteria of performance and output, the access to memory for a large-scale dictionary-scanning process is one involving considerable time; and the magnitude of the dictionary itself may be seriously limited by available storage space. The University of Washington group has based their operation upon the use of the high-speed photoscopic memory developed especially for this application by the International Telemeter Corporation. This memory device has a permanent storage of 30×10^6 bits with a random access time on the order of 0.05 seconds. The magnitude and speed of the memory have several significant implications from the basis of dictionary content.

The contents of the translation dictionary are subject to several approaches. If the dictionary memory is seriously limited in size, it is sometimes considered advisable to dissect words into stems, endings, and prefixes and then to use logical operations to assemble the related parts of a single word into the target language. In cases when memory

limitations are not considered, a saving of both logical circuitry and search time is effected by the storage of total words in the dictionary. This same general concept of complete storage can be extended to include many idioms and common phrases unitized in both languages which are being considered. Thus, in the University of Washington dictionary, stems are repeatedly stored with different endings and prefixes; many idioms are entered as single words, and dissection is minimized to conserve search time.

The determination of the contents of the dictionary is primarily a linguistic problem and one that need not be detailed here. It is sufficient to state that over 110 scientific Russian texts from 40 fields of science and technology were sampled. When the word lists from the texts were expanded into various grammatical forms, the dictionary contained in the order of 150,000 Russian entries. The number of associated English equivalents for these entries was approximately 500,000 words. Superficial examination of the lists of alternatives for given source entries gives evidence of redundancy. The equivalents, however, were carefully analyzed by both linguists and scientists in the field to minimize the number without destroying possible meaning.

In order to enter the logical processing operations following the dictionary output, it is necessary to include as a part of the dictionary entries information related to the grammatical usage of the particular entry and certain subroutines required for the processing of the word in question. This information is stored in "tags" which are considered as a part of the target equivalent in the dictionary. The dictionary output then yields both English equivalents and the data tags containing grammatical and related information. Further specification of the use of the processing tags will be made later in this paper.

Although it is premature to determine the number of words required for the translation of a language, preliminary investigation indicates that something in the order of 50×10^6 bits of storage will be required for the language alone, with perhaps another 40×10^6 bits required for the related grammatical tags. Since this is an extremely controversial subject among MT workers and linguists in general, any figures must be taken as the roughest of approximations.

Logical Processing

The most difficult parts of the general mechanical translation problem from the computer application standpoint is that dealing with the improvement of the dictionary output. Among those who are working on actual output processing as opposed to pure linguistic research, something of a common approach seems to be evolving.

At the present phase of development, the dictionary output must be on a word-for-word basis. The "word-for-word" nomenclature is misleading. It might be better stated that the dictionary output is in most cases obtained by considering one word of the source text at a time. In order to reduce redundancy, select among multiple equivalents, specify ambiguities, and insert words which are included in the usage of one language and not another, the output must be considered in context in blocks of several words at a time. General purpose computers or special purpose processing computers must be used to accept the dictionary output, store portions of that output, and by consideration of certain linguistic and logical procedures modify the output to clarify the intent of the author in terms of the target language.

Specification of Processing Operations. The techniques used in the specification of the required processing are of significance in the total logical processing operation. The first step in prescribing the processing is linguistic analysis of text material to determine where ambiguities exist and precisely what features of the sentence syntax uniquely specify the exact intended meaning. To facilitate the specification of the tests for computer programming, a system of notation has been developed at the University of Washington. For example, the dictionary output of a given Russian verb may be in the form

(they) are-chosen/taken-out/get,

in which parentheses indicate that the word may or may not be used in a given context and slash bars indicate that one of the alternatives must be used. The linguist tells the engineer that in the given syntax of the text being examined this may be either a personal or impersonal verb form class in the third person plural with no preceding nominative expression, but with a following nominative expression; and, in this case, the preceding (they) can always be omitted. The engineer will write:

$$_{I}V_{3PL} \cdot \{Ad \cup Pa\} \cdot \sim p_n E^n \cdot f_n E^n = \sim(\text{they}),$$

where:

Ad	= adverb
I^V	= impersonal verb
V_{3PL}	= verb in third person plural
Pa	= particle
p_n	= preceding in sentence by an undetermined number of words, but only words of distributional class {} may intervene.
E^n	= nominative expression
f_n	= following in sentence by an undetermined number of words, but only words of distributional class {} may intervene.
{}	= allowed intervening form class.
$\sim$	= negation
$(\cdot)$	= logical "and"
$\cup$	= logical "or."

Other notation symbols are, of course, required and used before a language can be completely specified.

After these expressions have been written, similarities often become apparent. Many instances arise when several expressions can be combined into one which is only slightly more complex but much more general.

After a large body of the text material has been analyzed and the processing expressions have been written, the expressions are grouped according to the distributional class or grammatical specification of the individual words. A flow chart organizing the processing for each of the distributional classes is then written for the particular computer being used; i.e., separate flow charts are developed for the processing of verbs, nouns, prepositions, and other distributional classes.

There are two principal advantages related to the use of the symbolic notation of the necessary processing steps: first, the expressions allow easy determination of whether or not sufficient information is available to completely specify and process the step; and second, the flow charts may be easily organized and written from the expressions.

The use of symbolic notation brings up an interesting possibility. The interpretive routines might be written for the symbolic expressions in such a way that the expressions themselves might be entered into the computer directly, allowing the computer practically to develop its own program. This is essentially the same type of computer technique which is currently being widely used in mathematical symbolical programming operations. The use of the IBM 650 precludes such an effort at this time, but investigations of the techniques which would be required are being made as the more applicable forms of programming develop.

Use of the IBM 650 Computer for Logical Processing. It has been indicated that the output of the word-for-word translation is quite vague and confusing. For the translation to be useful to the human reader, considerable improvement of the output material over the dictionary output is necessary. The syntactic or contextual rules which have been discussed are to permit the solution of certain representative intended-meaning problems.

The IBM 650 computer has been used at the University of Washington to perform the tests stated in symbolic notation which have been previously discussed. These tests are essentially expressions of linguistic rules which determine the meaning of a given word in a specific syntax. Implementation of these rules by computer has not been completed at this time. The intention has been to develop a set of representative routines by which large quantities of text are then processed, finally reevaluating and expanding the processes to resolve most of the remaining intended-meaning problems. The routines which have been emphasized at this time are representative ones for resolving ambiguities of verb, substantive (noun), conjunction, and certain other classes. In addition, the rule of agreement of substantives with their modifying adjectives and governing prepositions is used to solve certain intended-meaning problems.

The input of the processing operations has been made up of cards which duplicate the output of the word-for-word translation dictionary. The computer then is used only for testing the logical processing procedures and not for the translation dictionary look-up. Because of the limited storage, it has been impossible to store all of the logical processing programs on the drum at one time. The program therefore has been divided into three sections: the first concerns the rule of agreement of the substantive with the modifying adjectives and governing prepositions; the second and third deal with substantive, conjunction, verb, and certain multiple distributional class processing patterns. (See Figures 1 and 2.)

Generally, the text material is processed by loading the program and text deck into the computer. The computer punches out another card deck which is similar to the input text deck except that certain modifications are made to solve some of the intended-meaning problems. This process is repeated through the three rounds of processing and then through a final interpret round of operation which provides for the insertion of certain English prepositions and the omission of certain word equivalents which the processing rounds have determined to be unnecessary. After the interpret routine, the output deck may be introduced into the accounting machine to give a print-out of the processed translation.

The first round of processing considers the rule that Russian substantives must agree with the adjectives which modify them in gender, number, and case. Prepositions must agree with the substantives which they govern in case. Also, the preposition in Russian always precedes the substantive (and the adjectives and adverbs which modify the substantive) in the sentence. We also assume that the adjective always precedes the substantive which it modifies in the sentence. Occasionally this does not hold true in Russian, but such cases will not be handled in the first round of processing since the solution would involve more than the simple matching procedure which is used in the first round. This assumption will not introduce any errors into the solution; it will only make the solution incomplete.

The logical equations for the first round of processing may be written as follows:

$(P \cup A \cup A^P)_{.*} \cdot \{A\}_{.*} f_n (A \cup A^P \cup S \cup S^P)_{.*} \rightarrow \cap$,

$(A \cup A^P \cup S \cup S^P)_{.*} \cdot \{A\} p_n (A \cup A^P \cup P)_{.*} \rightarrow \cap \cdot \sim P^E$,

where:

P = preposition
A = adjective
A^P = pro-adjective
S = substantive
S^P = pro-substantive
P^E = English preposition on right-hand side of the expression only
$()_{.*} \ldots ()_{.*}$ = words denoted by the bracketed terms must have one case in common.
$\cap$ = take the intersection of the case possibilities of words denoted by $()_{.*}$.

The first equation prescribes that if a preposition, adjective, or pro-adjective is encountered the machine is to test succeeding words for adjectives, pro-adjectives, a substantive, or a pro-substantive, and is to take the logical intersection of the case possibilities for these words. The intersection then gives the case possibilities for the word which is being processed. The first equation also denotes that the only allowable intervening words are adjectives (denoted by $\{A\}$) and also adverbs and particles which are implied in the equations since they may come anywhere.

The second equation states that, if an adjective, pro-adjective, a substantive, or a pro-substantive is encountered, preceding words should be checked in exactly the same way as the succeeding words in the case of the first equation, and, if the test gives a positive result, the case intersection is taken as before, but, in addition, in this case no English prepositions are to be inserted in the sentence immediately before the word which is being processed.

The processing is not mechanized in quite the way that the equations imply. When a preposition is encountered, the case information about the preposition is compared with that of succeeding adjectives and the succeeding substantive as described, but the modification of the case tags is performed not only on the preposition but also on the associated adjectives and the substantive. Similarly, in the case when no preposition is encountered, upon encountering an adjective a similar procedure is followed with respect to succeeding adjectives and a substantive, with modifications being performed simultaneously on all associated word tags with respect to their case information.

In order to illustrate the clutter of the word-for-word dictionary output and the action of logical processing in clarification of the output, an example will be given showing the original text, the dictionary output and the output of the first round of processing.

Последнее достигается умелым выбором частного случая общих законов явлений, связывающих величины, единицы которых входят в определение производной единицы.

The word-for-word translation will be as follows:

Last/latter is-attained/reached (to/for) (by/with/as) choice/election (of) private/particular/quotient/partial (of) case / chance / occurrence (of) general / common / total (of) laws (of) appearance / phenomena/symptoms, (of) tying / connecting / knitting (of) magnitude/quantity(s), (of) unit/one(s) (of) which enter-into definition / determination / attribute (of) (to/for) (by/with/as) derivative (of) unit/one(s).

The processed translation after the first round is as follows:

Last/latter is-attained/reached by/with/as skillful choice/election of private/particular/quotient/partial case / chance / occurrence of general / common / total laws of appearances / phenomena / symptoms, (of) tying / connecting / knitting (of) magnitude / quantity(s), (of) unit/one(s) (of) which enter-into definition/determination/attribute of derivative unit/one.

In this example the first round of processing is the most effective in improvement of the output. The word-for-word translation contains 62 words, while the processed translation contains only 49 words.

The information contribution of the processing may be easily calculated from the defining equation:

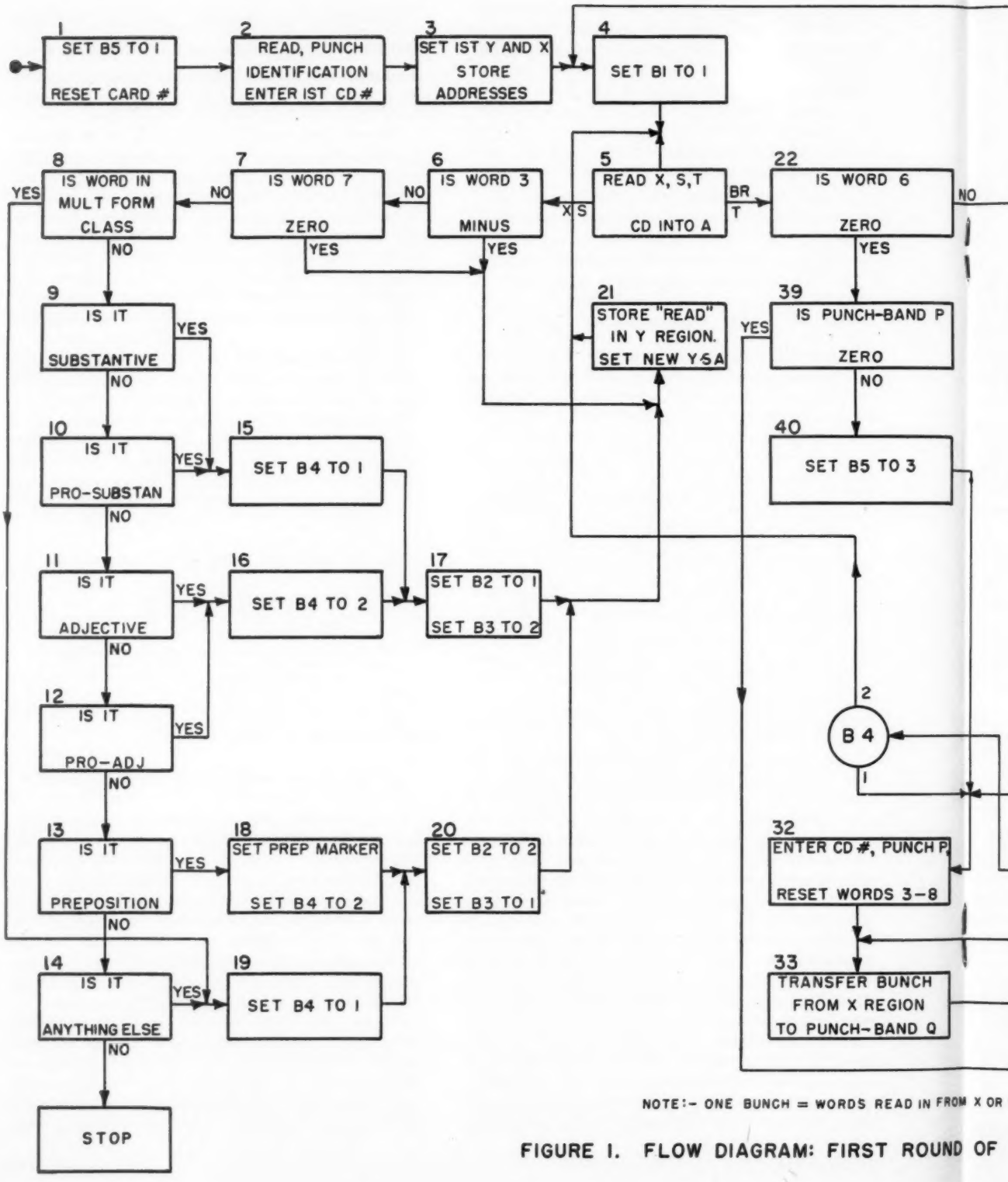
$$I_i = \frac{\log_2 \dfrac{\text{(no. possible sequences in w-for-w trans.)}}{\text{(no. possible sequences in processed trans.)}}}{\log_2 \text{(no. possible sequences in w-for-w trans.)}}$$

and in this case turns out to be:

$$I_i = \frac{12.81}{35.31} = 0.363.$$

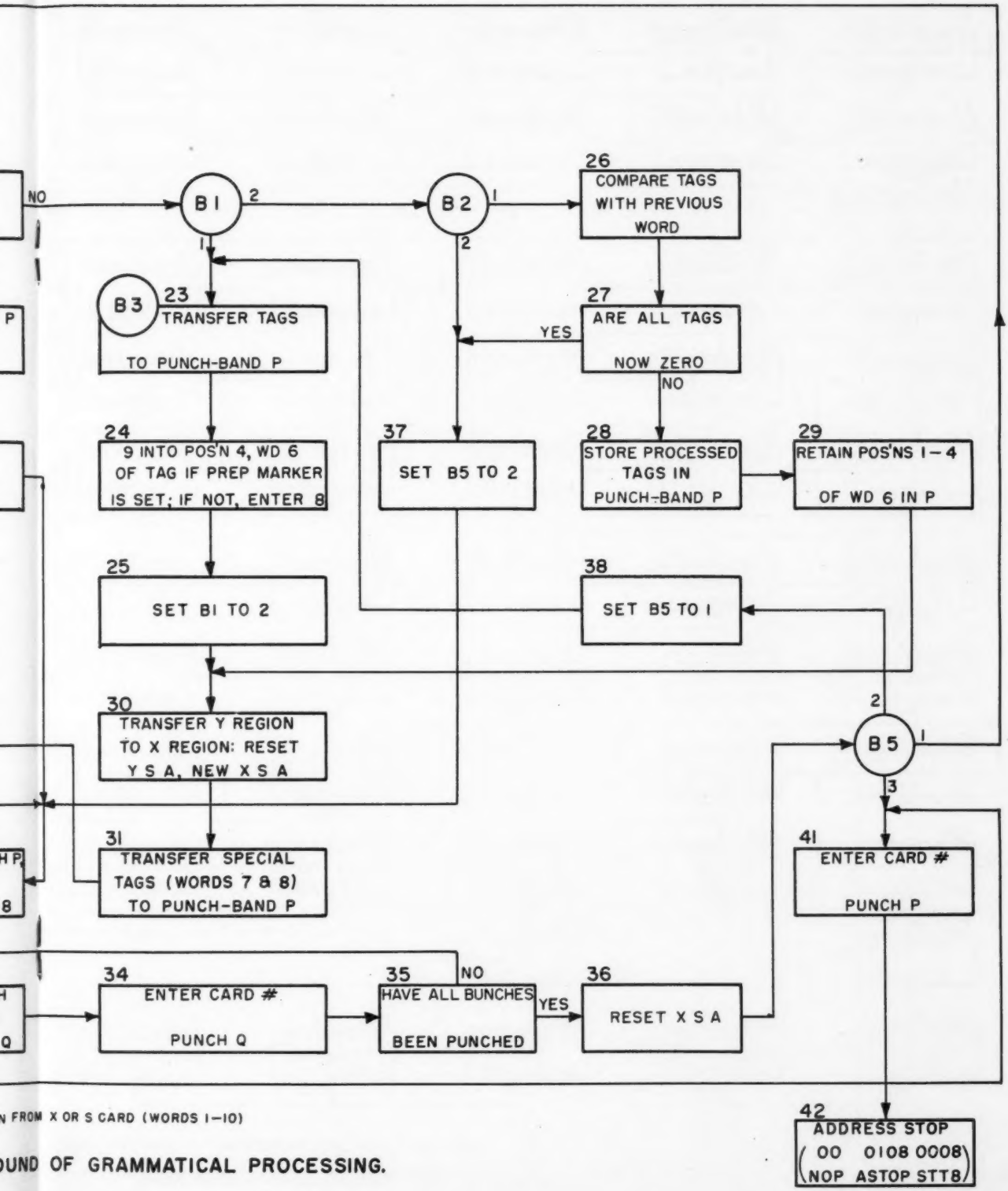
It will be noted that, in this part of the processing, a relatively pure matching operation is used in the programming. A word is identified as a particular part of speech by matching of the tags. If the word is a preposition or adjective, the intersection sum is taken with successive words until the substantive is reached. The individual tags are modified as the information common to the group replaces the more general information related to the individual words in isolation.

In the later rounds of processing, more involved processing equations are explored. Many of these require the examination of several words in sequence and an analysis of words preceding and following the word being tested. The computer was used to store and examine six words at a time in a survey storage



NOTE:- ONE BUNCH = WORDS READ IN FROM X OR

FIGURE I. FLOW DIAGRAM: FIRST ROUND OF



N FROM X OR S CARD (WORDS 1–10)

OUND OF GRAMMATICAL PROCESSING.

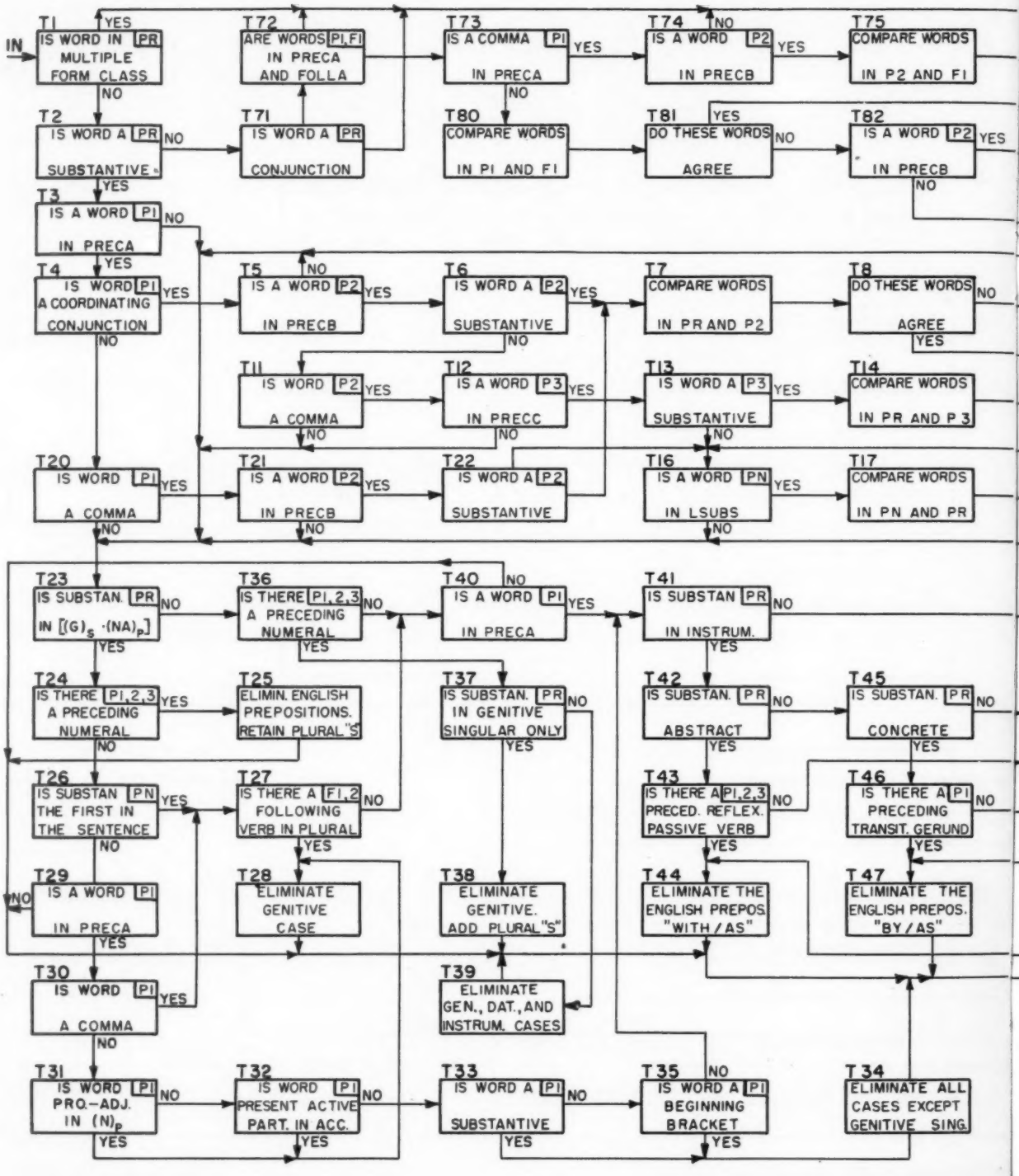
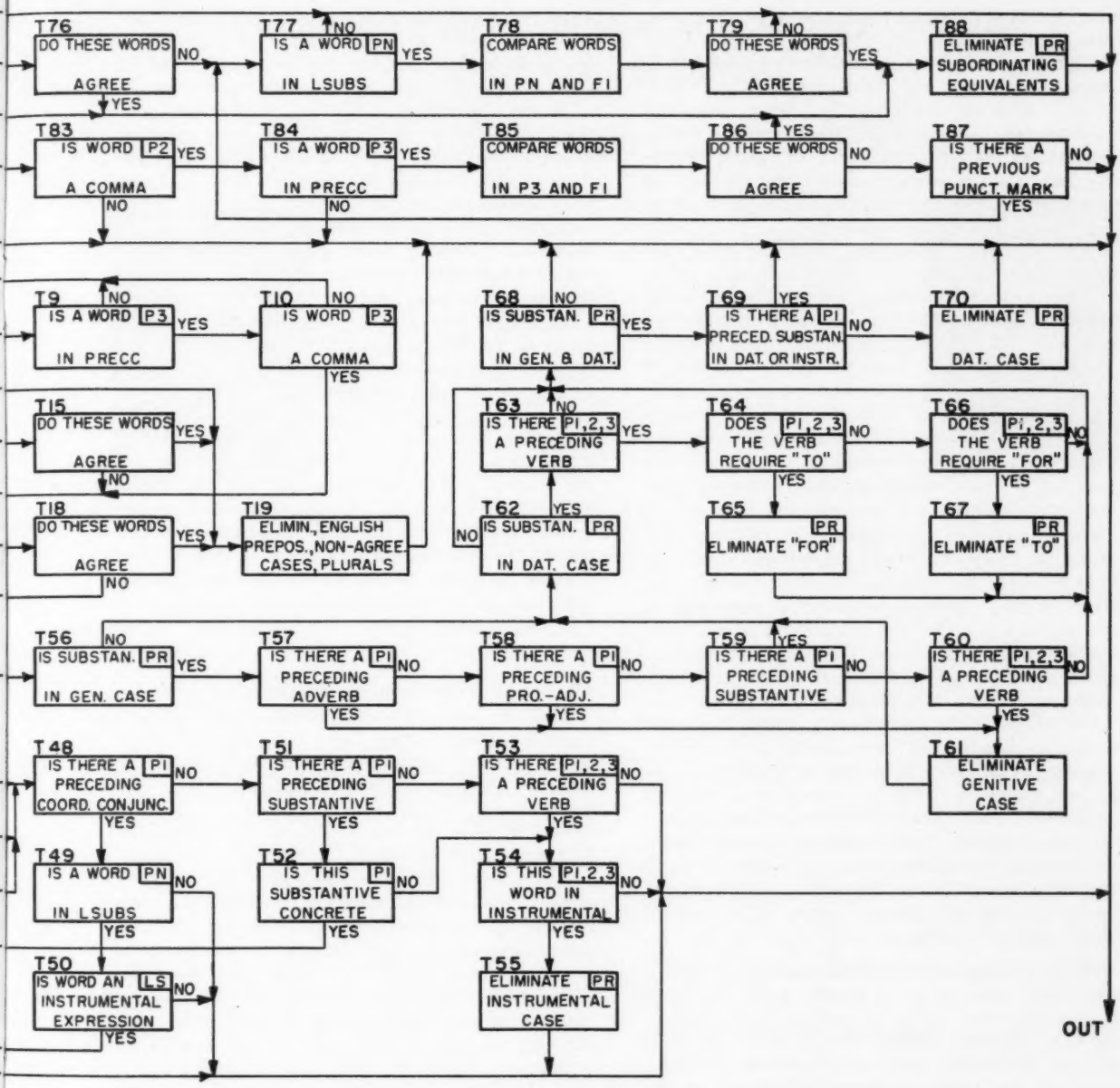


FIGURE 2. FLOW DIAGRAM: SECO



RAM: SECOND ROUND OF GRAMMATICAL PROCESSING

area; the word in question, two words following, and three words preceding it. The text is then stepped through the survey storage area in one-word increments. The second and third rounds of precessing are most efficiently carried out by what is essentially a combination between matching procedures and a programmed search process. For any given processing test, the computer examines the contents of the six-word survey storage area to determine if the conditions of the test are satisfied.

Obviously, the grammatical processing tests cannot be efficiently made in isolation from each other. A group of tests considering the same grammatical class of word are related in a common operation by a generalized flow diagram, and the program branches to determine which, if any, of the related processing equations are satisfied in a given context as it appears in the text. It would be possible to carry the pure matching methods into this processing, but investigation indicates that optimal use of the computer can be best obtained by means of the combination matching and search methods.

There are certain multiple-meaning problems that cannot be directly resolved by grammatical testing. As an example, the same Russian word can represent either "matrix," as the word appears in mathematics, or a tool maker's "die." To reduce this type of multiple equivalence, a scheme has been implemented which requires the identification of all dictionary words as to fields of application. The specification of field of application appears as a part of the grammatical specification tag; when a word has different meanings in different fields, this will be noted. As the text is processed, the common field or fields of application are determined and the unrelated equivalents are dropped. This matching procedure can, under certain conditions, yield results which are not completely satisfactory in translation; however, the general concept and process is one which may be used in future investigations.

Word Arrangement and Block Analysis.[1] A problem of translation which is related to the difference of structure between the two languages is that of word arrangement. The translation so far described has been essentially in the same order as the input text. In many languages, this could present an extremely serious problem. Fortunately, Russian technical literature uses word order which is usually acceptable in English. This relationship of word order, however, is not uniform, and the problem requires investigation. One approach to the general problem is the identification and separation of different blocks of the text sentences. After this has been achieved, word rearrangement within the blocks can be determined by matching procedures; rearrangement of blocks within the sentence can be accomplished by a combination of matching and search operations.

At the University of Washington, the identification and isolation of blocks within sentences was initially done using Greek as the source language; then it was extended to Russian. Noun phrases, prepositional phrases, verbal forms, adverbial clauses, and coordinating conjunction forms are isolated and identified. The word order within the blocks is not rigid but follows a general set of forms which allows the use of matching procedures and Boolean intersection and union sums to identify and determine the limits of the blocks. Since the IBM 650 computer operates in biquinary arithmetic, it is not capable of performing direct intersection summations. Special sub-routines are therefore used to transform normal arithmetic summation results to the corresponding intersection sums. As more complicated word blocks are studied, a combination of matching and search procedures is required. It should not be implied that methods of word rearrangement have been completely developed at the University of Washington. Specific programs and operations are currently in operation at the block analysis and isolation level, but little application work has been carried out in the rearrangement problem.

Mechanical Translation Economics

Comparison of the costs of human translation with those for machine translation is rather difficult to make. Current machine translation development is at the research phase rather than in production. Resultantly any estimates of the ultimate cost of a refined machine translation process must necessarily be approximate and involve considerable extrapolation. There are many processes that are not currently being considered by mechanical translation techniques; the processing of mathematical developments, placing equations at the proper place on a printed page, graphical developments, flow diagrams and other representations important to the meaning of technical literature have been neglected. One type of text material which might be used for comparison is scientific material which is not mathematical or highly specialized in nature; i.e., text that could be translated on a typewriter by a nonspecialist with a general scientific background. This material can be translated for roughly one cent per word by human translators.

If the text input to the mechanical translator is to be either punched tape or cards, the experience at the University of Washington has been that the cost of punching text by employees of average ability

(Continued on page 25)

[1] See "Noun Phrase Analysis Using the IBM 650 Computer," *The Trend in Engineering*. April, 1957.

Radiation Pattern Synthesis with Sources Located On a Conical Surface*

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A. Ishimaru

Introduction

The purpose of a transmitting antenna is to radiate the electro-magnetic energy in a required manner in various directions of space. When the antenna structure and the source are known, the problem of finding the radiation fields is called an "analysis." When the antenna structure and the desired radiation pattern are known, the problem of finding the source function is called a "synthesis." In this present work, we wish to present various methods of solving the synthesis problem when the sources are located on a surface of a cone.

Radiation Pattern Synthesis

In order to solve a synthesis problem, we employ various approaches to formulate the relationship between the sources and the radiation field. The approach by solving the boundary value problem is fundamental but not suitable for the synthesis problem because of the complex expression of the Green function. The Huggens-Green formulation is usually used for the aperture synthesis problem. The formulation using current source distribution is employed to solve the synthesis of the linear array problem.

The solution of the linear array synthesis problem is carried out through the use of the Fourier method and the Tchebyscheff polynomial. The Woodward method and the Taylor optimum design are used for the synthesis of the rectangular aperture antenna. The Schmidt orthogonalization method is used for the circular aperture problem.

For our synthesis problem, the sources are located on a conical surface, and the expression of the radiation pattern involves the product of the Bessel and exponential functions.

Analysis of Conical Problem

Let us consider the electric dipoles located on the circumferences of the cone as shown in Fig. 1. The circumferences are equidistant from each other. The dipoles are oriented circumferentially. The number of dipoles around the cone S is assumed to be infinitely large and the dipole strength P is reduced in such a manner that $A_n(\phi_0) = S\,P_n(\phi_0)$ is constant. When the source distribution is independent of ϕ_0, the radiation field can be expressed as follows:

G. Held

$$\left.\begin{aligned} E_\theta &= -j\frac{\omega\mu}{4\pi R}\,e^{-jKR}F_\theta\,, \\ E_\phi &= -j\frac{\omega\mu}{4\pi R}\,e^{-jKR}F_\phi\,, \end{aligned}\right\} \tag{1}$$

$$\left.\begin{aligned} F_\theta &= 0\,, \\ F_\phi &= \sum_n A_n\,j J_1(z_n)\,e^{jK\rho_n\cos\theta_0\cos\theta}\,. \end{aligned}\right\} \tag{2}$$

The field pattern $y(\theta)$ is given by

$$\left.\begin{aligned} y(\theta) &= \left|\sum_n A_n J_1(z_n)\,e^{jK\rho_n\cos\theta_0\cos\theta}\right|, \\ z_n &= K\rho_n\sin\theta_0\sin\theta\,. \end{aligned}\right\} \tag{3}$$

Our synthesis problem is then to obtain the values of A_n in order to produce a prescribed radiation field pattern $y(\theta)$.

This source distribution does not produce the radiation at $\theta=0$, but the source with 2π phase shift around the cone produces the radiation in $\theta=0$ direction.

Synthesis on a Conical Surface

In order to obtain A_n in Eq. 3, various methods may be employed, depending on the locations of the sources.

When the sources are located in the region where circumference is less than 2, we have approximately

$$\begin{aligned} J_1(z_n) &\approx \frac{z_n}{2}\left(1-\frac{z_n^2}{8}\right), \\ &\approx \sin\theta\,(a_n+b_n x^2)\,, \end{aligned} \tag{4}$$

* An abstract of Mr. Ishimaru's thesis of the same title submitted as partial fulfillment of requirements for the degree of Ph.D. in Electrical Engineering.

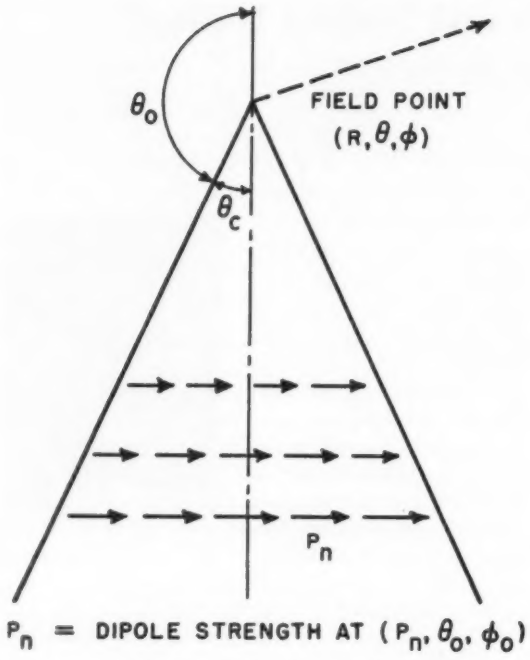

FIG. 1. TANGENTIAL ELECTRIC DIPOLES

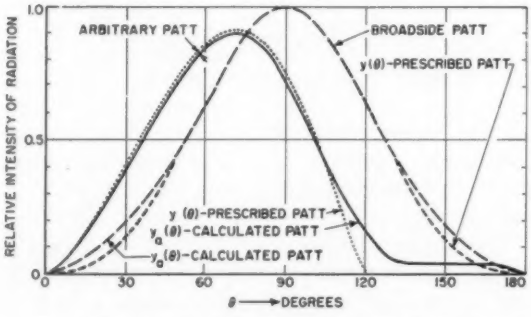

FIG. 2. EXAMPLE OF BRAODSIDE PATTERN AND OF ARBITARY PATTERN

where

$$x = K\rho_0 \cos\theta_c \cos\theta \,. \tag{5}$$

Letting

$$y(\theta) = \sin\theta f(\theta) \,, \tag{6}$$

we get

$$\begin{aligned} f(\theta) &= f(x) \\ &= \sum_n A_n (a_n + b_n x^2) e^{-jnx} \,. \end{aligned} \tag{7}$$

We can rewrite $f(x)$:

$$f(x) = f_1(x) + f_2(x) \,, \tag{8}$$

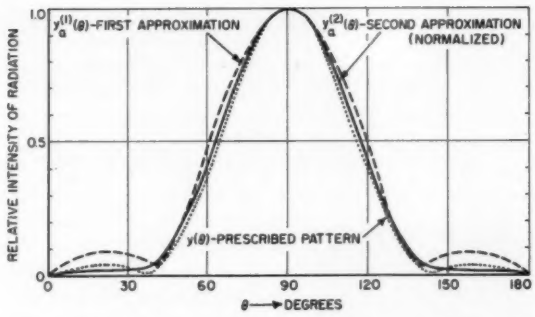

FIG. 3. EXAMPLE OF BROADSIDE TAPERED TCHEBYSCHEFF PATTERN

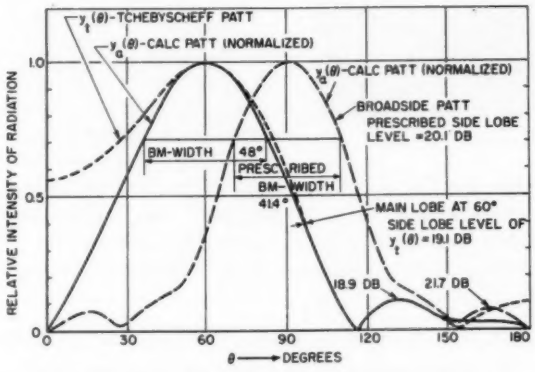

FIG. 4. EXAMPLE OF BROADSIDE PATTERN AND OF PATTERN WITH MAIN LOBE AT 60°

where

$$\left.\begin{aligned} f_1(x) &= \sum_n A_n a_n e^{-jnx} \,, \\ f_2(x) &= x^2 \sum_n A_n b_n e^{-jnx} \,. \end{aligned}\right\} \tag{9}$$

The function $f_1(x)$ is exactly the same expression as that of a linear array, and $f_2(x)$ represents the correction term due to the conical shape. To obtain the first approximation, we let

$$f(x) = f_1(x, A^{(1)}) \,. \tag{10}$$

The second approximation may be obtained by

$$f(x) - f_2(x, A^{(1)}) = f_1(x, A^{(2)}) \,. \tag{11}$$

It can be shown that $A^{(n)}$ converges for this source location. In Fig. 2 both the prescribed pattern and the calculated pattern with the second approximation are shown.

When the sources are located in the region where the circumference is approximately less than 4 wavelengths, we devise an expansion formula:

$$J_1(z\sin\theta)\,e^{jz_0\cos\theta} = \sin\theta\left[\frac{a_0}{2}+\sum_{m=1}^{\infty} a_m\cos(m\pi\cos\theta)+j\sum_{m=1}^{\infty} b_m\sin(m\pi\cos\theta)\right]$$

$$=\sin\theta\sum_{m=-\infty}^{+\infty} C_m\,e^{jm\pi\cos\theta}, \qquad (12)$$

where

$$C_m=\frac{1}{z}\left[(-1)^m\cos z_0-\cos\sqrt{z^2+(z_0-m\pi)^2}\right]. \qquad (13)$$

In the region mentioned, the value of C_m is greatest when $z_0=m\pi$, and this term contributes most to the radiation. The remainder of the terms may be taken into consideration by a successive approximation method. Figure 3 shows both the prescribed and the calculated pattern for this case.

When the sources are located far away from the cone tip, we choose the source location in such a manner that the maximum of the Bessel function coincides with the peak angle of the main beam. Figure 4 shows the example using this approach.

Conclusion

We have shown in this paper various methods of computing source function on a conical surface to produce a prescribed radiation pattern. It is hoped that this work will provide a useful means of designing practical antennas having a conical structure.

Logical Processing in Mechanical Translation

(Continued from page 22)

is on the order of 0.85 cent per word. The cost of the dictionary search on the International Telemeter Corporation memory device and the print-out combined is approximately 0.10 cent per word. The logical processing costs, even assuming a computer of the magnitude of the IBM 701, would be about 0.50 cent per word. This yields a comparison of 1.00 cent per word for human translation versus about 1.45 cents per word for mechanical translation.

In a comparison of translation times for the same sample, the punching of the text alone for MT requires nearly the same time as the complete translation process by human means. The actual computer time required is negligible.

Without the development of a high-speed electronic reader, machine translation of languages cannot be justified on the basis of cost alone. For many applications, however, it is likely that MT will not have to be justified on a cost-per-word basis. The electronic reader is of tremendous importance to MT; a really high-speed and efficient electronic reader could reduce costs well below the cost of human translation and increase the total speed of mechanical translation far beyond that of human translation.

Summary

Mechanical translation of languages by means of digital computers is an extremely diverse and interesting illustration of logical computer applications. Current development in the area is not so much oriented toward production practices as it is used as a research device in the development of the theory of methods of translation. The experience of using a medium sized computer is invaluable in determining the final computer to be used in production operation. It is apparent that either a large high-speed, general purpose digital computer or a high-speed, special purpose, logically oriented digital computer can be used in conjunction with the dictionary storage device.

The purpose of the work at the University of Washington has not been to perform complete and perfect translation, but to choose representative operations that are significant in the translation process and apply them to the computer at our disposal. The work has been carried out as a coordinated effort between the linguistic and engineering staff of the project. The specification of the logical procedures and programming have been largely the responsibility of the engineering staff, while the linguistic analysis of the text has rested with the linguists. The direction of the work has been shared by consideration of the over-all linguistic goals and the application methods and capabilities of computer operation.

The logical processing work currently developed reduces the total "clutter," or output unnecessary for meaning in a particular context in the results of the processing operation, to roughly 50 per cent of that of the dictionary output. Indications are that further work will lead to results in which the processing output is in the same or better form than would be obtained from a human translator.

Machine translation will probably be unable to compete with human translation on either a time or economic basis until a high-speed electronic reader has been developed that is satisfactory in a translation application.

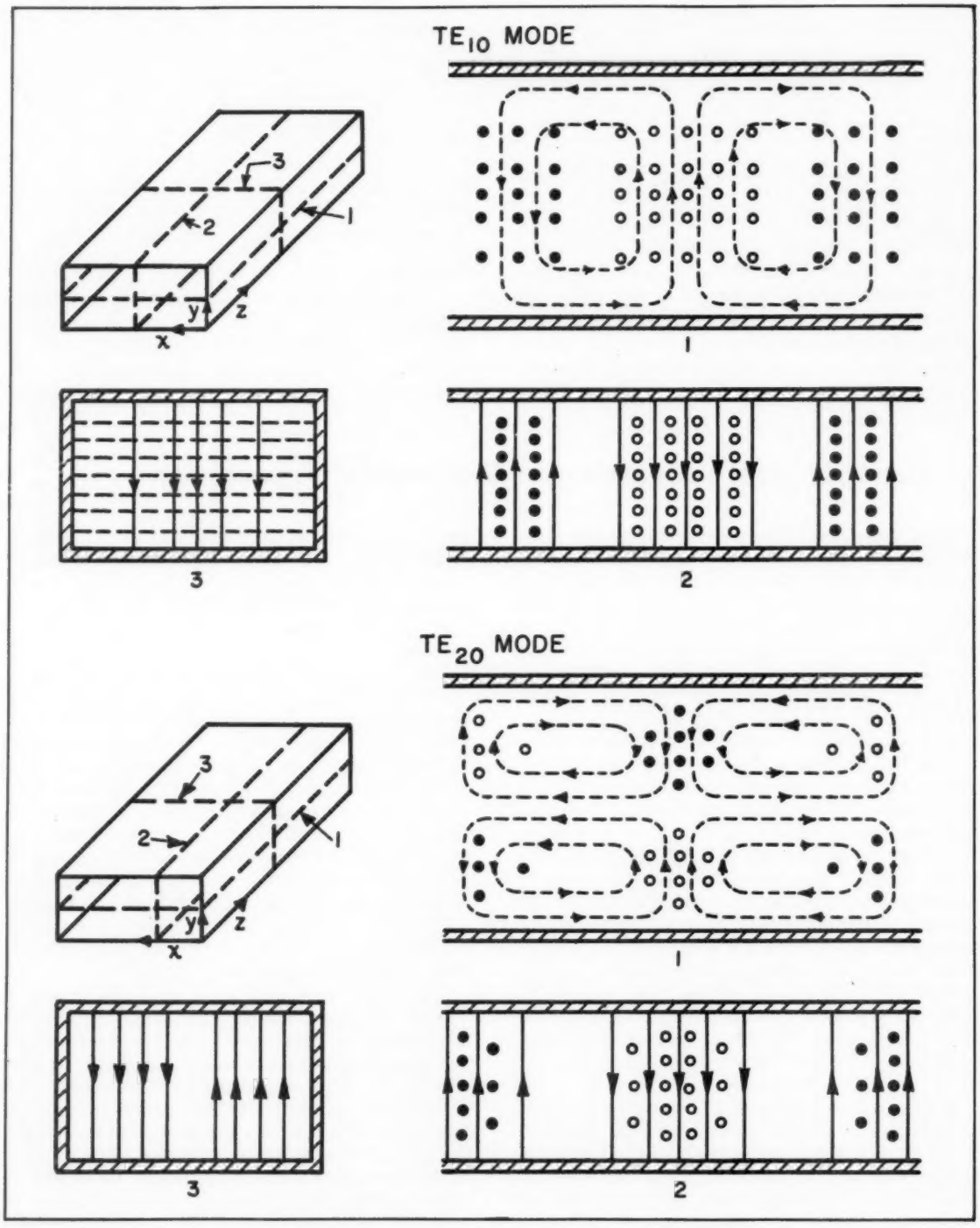

FIG. 1. FIELD CONFIGURATIONS OF THE TE_{10} AND TE_{20} MODES

A BROADBAND DUAL-MODE TRANSDUCER*

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The use of several propagating modes of electromagnetic energy in a wave guide is becoming increasingly important. Although the most common use of waveguides involves the propagation of the dominant TE_{10} mode in a rectangular cross section, some of the unusual characteristics of the higher order modes are being used to great advantage. The low loss properties of the circular TE modes overcome the problem of transmitting signals of millimeter wavelength over large distances.[1] Some of the complex field configurations necessary for the operation of such microwave devices as circular polarizers,[2] circulators,[3] unilines,[4] and antennas,[5,6,7,8] are possible only through the application of multimode theory.

The development of a dual-mode transducer was motivated by the unusual excitation requirements of the flush-mounted antennas required on modern supersonic and hypersonic aircraft. The purpose of this study was to develop a broadband transducer for independently exciting the dominant TE_{10} mode and the higher order TE_{20} mode in a rectangular waveguide. The transducer was needed for exciting experimental flush-mounted cavity antennas. The independent control of the amplitude and phase of each mode allowed a wide range of possible field distributions at the antenna aperture, resulting in some degree of electronic control over the associated radiation patterns.[9] By the use of coupled wave theory, a transducer was developed which operated satisfactorily over the major portion of the usable bandwith of X-band waveguide.

Theory

The electromagnetic field in a waveguide may be determined by solving Maxwell's field equations in a coordinate system applicable to the shape of the guide. The solution will be a superposition of an infinite number of modes or wave types. The electric and magnetic field components of each mode may be factored into form functions depending only on the transverse coordinates and into amplitude functions depending on the direction of propagation in the guide. Owing to the orthogonality property of the modes, there can be no energy coupling between them as they propagate down a guide of uniform cross section. Consequently, a waveguide with no discontinuities propagating n modes behaves as n separate waveguides, each carrying a fundamental mode. The two modes of interest in this study, the dominant TE_{10} mode and the TE_{20} mode, have fields as shown in Fig. 1. The electric and magnetic fields are denoted by solid and broken lines, respectively, and the electric fields are given by

G. Held

$$Ey_1 = A_1 \sin\frac{\pi}{a}x\, e^{-j\beta_1 z} \tag{1}$$

for the TE_{10} mode, and

$$Ey_2 = A_2 \sin\frac{2\pi}{a}x\, e^{-j\beta_2 z} \tag{2}$$

for the TE_{20} mode. The phase constants,

$$\beta_1 = \sqrt{\omega^2\mu\epsilon - \left(\frac{\pi}{a}\right)^2}, \tag{3}$$

$$\beta_2 = \sqrt{\omega^2\mu l - \left(\frac{2\pi}{a}\right)^2}, \tag{4}$$

may be real or imaginary, depending on the values of ω and waveguide width, a. Real phase constants allow the modes to propagate, while imaginary values correspond to nonpropagating or "cut off" modes. A waveguide mode may be excited by applying an exciting source in such a way that the field of the source corresponds in some manner to the field of the desired mode. Generally the field configuration necessary to excite a desired mode will also excite other modes. Suppression of the undesired modes may be obtained by a judicious choice of waveguide size, by taking advantage of the symmetry or nonsymmetry of the required modes when choosing an exciter, or by the use of mode filters.

*Condensed and arranged by the authors from Mr. Guy's thesis submitted as partial fulfillment of the requirements for the degree of M.S. in Electrical Engineering.

The coupling method used in this study is illustrated in Fig. 2. The side wall of a standard X-band waveguide was removed and the open side of the guide was placed symmetrically on a slot cut in the broad face of a larger guide capable of supporting both the TE_{10} and the TE_{20} modes. The TE_{10} mode field of the small guide will excite a TE_{20} mode in the large guide in the manner shown in the insert in Fig. 2. Since the antisymmetrical field at the aperture cannot excite the symmetrical TE_{10} mode in the large guide, that mode may be excited independently by a tapered transition placed at the end of the large guide as shown in Fig. 2. The relation between the length of the coupling aperture and the amount of power coupled between the small TE_{20} mode feed guide and the dual-mode guide may be obtained by using the coupled wave theory advanced by Miller.[10] If we denote the feed and dual-mode guides by lines 1 and 2, respectively, and assume no loss, the variation of wave amplitude with distance z along the aperture may be written as

$$\frac{dE_1}{dz} = -j(\beta_1+\beta_{11})+j\beta_{12}E_2\,, \tag{5}$$

and

$$\frac{dE_2}{dz} = -j(\beta_2+\beta_{22})E_2+j\beta_{12}E_1\,, \tag{6}$$

where

β_{11}, β_{22} represent coupling reaction on lines 1 and 2, respectively,

β_{12} represents the effect of coupling between the lines,

β_1 is the uncoupled phase constant for the TE_{10} mode in line 1,

β_2 is the uncoupled phase constant for the TE_{20} mode in line 2,

E_1, E_2 are the amplitude functions of the modes in lines 1 and 2, respectively.

Noting that the total power must be a constant and letting

$$\left.\begin{aligned}\beta_1^1 &= \beta_1+\beta_{11}-\beta_{12}\\ \beta_2^1 &= \beta_2+\beta_{22}-\beta_{12}\end{aligned}\right\}, \tag{7}$$

one may allow $E_1=1$ and $E_2=0$ at $z=0$ to obtain

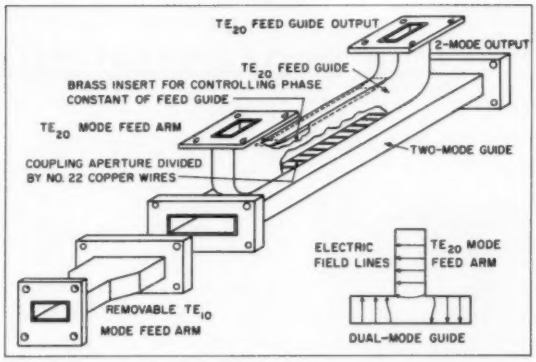
TE20 FEED GUIDE OUTPUT
2-MODE OUTPUT
TE20 FEED GUIDE
BRASS INSERT FOR CONTROLLING PHASE CONSTANT OF FEED GUIDE
TE20 MODE FEED ARM
TWO-MODE GUIDE
COUPLING APERTURE DIVIDED BY NO. 22 COPPER WIRES
ELECTRIC FIELD LINES
TE20 MODE FEED ARM
REMOVABLE TE10 MODE FEED ARM
DUAL-MODE GUIDE

FIG. 2. BROADBAND DUAL-MODE TRANSDUCER
Insert shows the electric field configuration at the transverse cross section of the transducer.

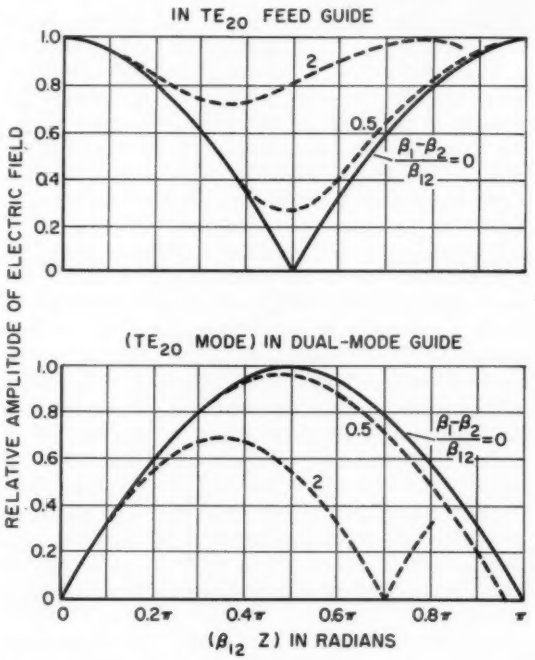

FIG. 3. WAVE AMPLITUDE VS COUPLING IN THE DUAL-MODE TRANSDUCER

$$E_1 = \left\{\cos\left[\sqrt{\frac{(\beta_1^1-\beta_2^1)^2}{4\beta_{12}^2}+1}\;\beta_{12}z\right] - j\frac{(\beta_1^1-\beta_2^1)}{2\beta_{12}}\frac{1}{\sqrt{\frac{(\beta_1^1-\beta_2^1)^2}{4\beta_{12}^2}+1}}\sin\left[\sqrt{\frac{(\beta_1^{12}-\beta_2^{12})}{4\beta_{12}^2}+1}\;\beta_{12}z\right]\right\} e^{-j\left(\beta_{12}+\frac{\beta_1^1+\beta_2^1}{2}\right)z}, \tag{8}$$

and

$$E_2 = \frac{j}{\sqrt{\frac{(\beta_1^{12}-\beta_2^{12})}{4\beta_{12}^2}+1}}\sin\left[\sqrt{\frac{(\beta_1^1+\beta_2^1)^2}{4\beta_{12}^2}+1}\;\beta_{12}z\right] e^{-j\left(\beta_{12}+\frac{\beta_1^1+\beta_2^1}{2}\right)z}. \tag{9}$$

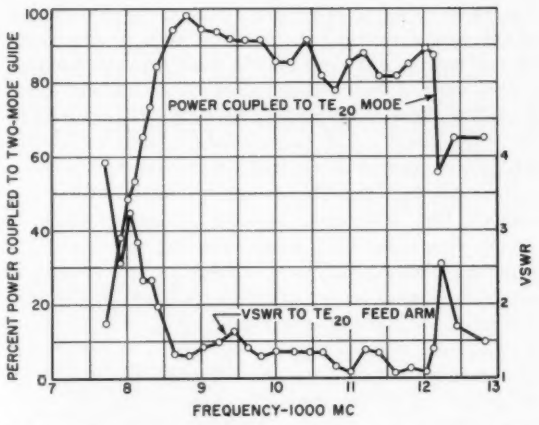

FIG. 4. FREQUENCY DEPENDENCE OF THE COUPLED TE_{20} MODE POWER AND THE VSWR TO THE TE_{20} MODE FEED ARM OF THE DUAL-MODE TRANSDUCER

When $\beta_1^1=\beta_2^1=\beta^1$, Eqs. 8 and 9 reduce, respectively, to

$$E_1=\cos\beta_{12}z e^{-j(\beta_{12}+\beta^1)z}, \tag{10}$$

$$E_2=j\sin\beta_{12}z e^{-j(\beta_{12}+\beta^1)z}. \tag{11}$$

The amplitude variation due to coupling between the lines is plotted in Fig. 3. The curves indicate a cyclic variation of amplitude of the fields in each line, and show that total power transfer occurs only when $\beta_1^1=\beta_2^1$. Since the feed guide does not have the same geometry as the dual-mode guide, the reaction of coupling on the phase constant is different in the two lines. The value of β_{22} is slightly larger than that of β_{11}, so from Eq. 7 β_1 must be made slightly larger than β_2 in order that $\beta_1^1=\beta_2^1$. From Eqs. 3 and 4 it can be seen that, by letting the feed-guide width equal less than one half the dual-mode guide width, the required phase constants may be obtained. Total energy transfer in the forward direction may then be obtained by allowing $\beta_{12}z=\pi/2$. Destructive interference prevents the coupling of energy in the backward direction. By allowing $\beta_{12}z$ to take on values less than $\pi/2$, an arbitrary division of power between the lines may be selected. To prevent the energy from reflecting back and forth between the ends of the aperture and so disturbing the coupling mechanism, the aperture may be divided into small sections by wires as shown in Fig. 2. For a given length of aperture, β_{12} will decrease as the aperture sections are increased, so a compromise must be made between the number of sections and the total aperture length.

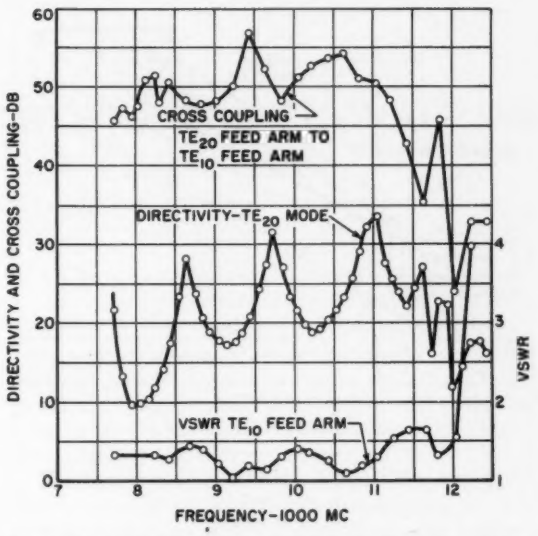

FIG. 5. FREQUENCY DEPENDENCE OF THE CROSS COUPLING, DIRECTIVITY, AND VSWR TO THE TE_{10} FEED ARM OF THE DUAL-MODE TRANSDUCER

Procedure

The transducer shown in Fig. 2 was constructed with 0.4-in. by 1.6-in. ID waveguide for the dual-mode line and 0.4-in. by 0.9-in. ID (standard X-band) waveguide for the TE_{20} mode feed line. A brass insert was used in the small guide for obtaining the correct phase constant. The wall was 0.05 in. thick. In order to limit the size of the transducer, a maximum coupling length of four inches was used. Experimental results indicate that 8 equally spaced No. 22 copper wires in the aperture, which was 4.0 in. by 0.4 in., and a feed guide 0.4 in. by 0.755 in. ID were required for maximum coupling. The end of the feed guide was terminated with a load, and the frequency dependence of the coupled power to the TE_{20} mode and the VSWR at the TE_{20} feed arm were measured. The results are shown in Fig. 4. The input VSWR was below 2, and over 80 per cent of the power was coupled to the TE_{20} mode over most of the 8.2- to 12.4-kmc usable range of the waveguide. The low-frequency drop-off of coupled power was due to the waveguide approaching cut-off, while the high-frequency drop-off was due to the sections in the coupling aperture approaching resonance, thereby causing a rapid change of coupling versus frequency. It follows that the bandwidth may be increased by decreasing the size of the sections and compensating for the decrease in coupling by increasing the aperture length. Other characteristics of the transducer that were of interest included the cross coupling and directivity of the TE_{20} mode feed.

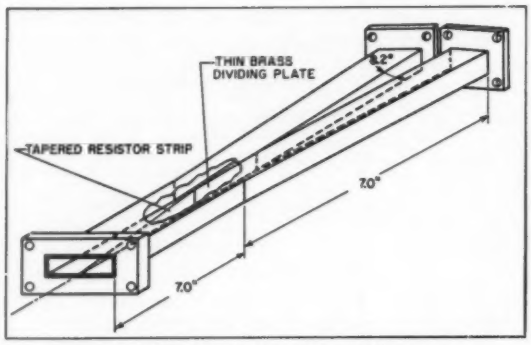

FIG. 6. THE TE_{20} MODE POWER SPLITTER

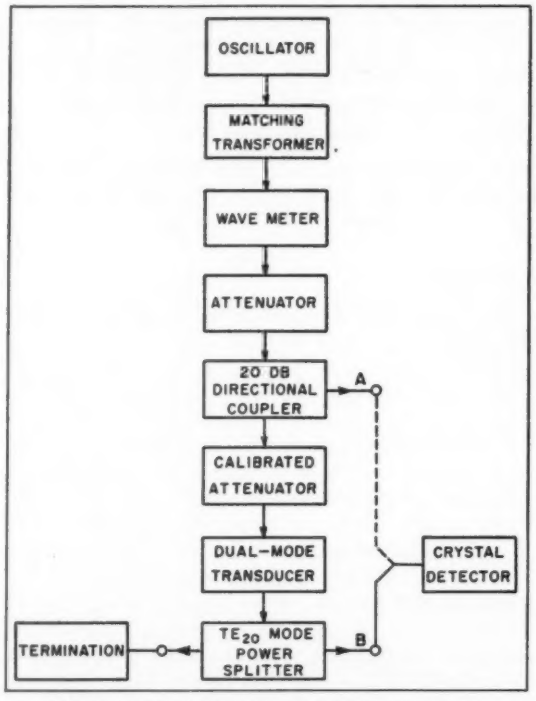

FIG. 7. BLOCK DIAGRAM OF THE TRANSDUCER EQUIPMENT

The cross coupling is defined as the ratio, in decibels, of the power incident on the feed arm of one mode to the power scattered to the feed arm of another mode, with all arms terminated in a matched load. The directivity is defined as the ratio, in decibels, of the TE_{20} mode power in the forward direction to the TE_{20} mode power in the backward direction. Figure 5 indicates that the cross coupling and VSWR were low and the directivity high over the same frequency range where the TE_{20} mode coupling was high. In order to measure the coupled TE_{20} mode power, it was necessary to construct the power splitter shown in Fig. 6. It is a device for splitting the TE_{20} power evenly into standard ½-in. by 1-in. waveguides so that standard X-band detectors and bolometers can be used for detecting the output. A 4-in. resistor strip was added at the center of two two-mode input arms of the power splitter in order to attenuate any TE_{10} power that might have been present. The TE_{20} power may be measured by connecting the power splitter to the TE_{20} mode output, terminating one arm of the power splitter with a matched load, and measuring the power from the remaining arm with a matched detector. The measured power will be 3 db below the TE_{20} power incident to the power splitter.

The block diagram and a photograph of the equipment used to determine the characteristics of the dual-mode transducer are shown in Figs. 7 and 8, respectively. The amount of coupled power to the TE_{20} mode of the transducer at each frequency was determined in the following manner. Attenuator 1 was set for 20 db to isolate the power source from the load. Power was fed to the TE_{20} mode feed arm of the transducer with the remaining arms terminated by matched loads. The relative incident power level was noted by connecting a matched detector to arm A of the calibrated 20-db directional coupler. The calibrated attenuator was then set for maximum attenuation, and the two-mode load was replaced by the power splitter. One arm of the power splitter was terminated by a matched load and the other arm, B, was terminated with the same matched

(Continued on page 36)

FIG. 8. EQUIPMENT FOR DETERMINING THE CHARACTERISTICS OF THE DUAL-MODE TRANSDUCER

THE SOLUTION OF LARGE NETWORKS BY SECTIONALIZING

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Professor of Electrical Engineering

L. J. Lewis

The solutions of large networks with many variables pose numerous problems in computation, whether the calculation is performed manually or by means of a computer, simply because of the sheer size of the systems. Among several procedures for reducing the complexity, one method in particular has special merit under certain conditions. This procedure has been called "the method of tearing" by Gabriel Kron who has exploited it effectively in numerous applications.[1,2] Because the exposition in specific applications has often been considered in conjunction with the use of "tensors," "transformations," and "matrices," the basic simplicity of the idea perhaps is not generally appreciated. It is the purpose of this discussion to present a physical explanation of the procedure, based on relatively elementary concepts, without recourse to the more generalized procedures of analysis.

This basic procedure rests solely on the properties of a linear system. The topology, or physical layout, of a system is important, however, in determining how effective the method will be in reducing the complexity of calculation. In view of the objective of this presentation only simple examples will be discussed; it should be fairly obvious thereafter how other cases may be fitted into the general framework.

As a first example, Figure 1 portrays an electrical network containing a multitude of linear elements, activated by a group of current sources. A classical problem would be to determine the voltages of all the nodes with respect to ground, with element values given and the sources specified. The "standard" procedure would consist of formulating a set of simultaneous equations by Kirchhoff's Laws in terms of all the unknowns, and solving the set of equations. Because the system is large, the number of equations, equal to the number of unknowns, is also large; hence the task of calculation may be considerable.

To simplify the process, it is proposed to substitute for the single large calculation, a number of shorter and simpler calculations, whose composite values are equivalent to those of the single solution. The network of Figure 1 has the special feature that each node is directly connected to only a limited number of other nodes. It is this characteristic which permits the simplification.

First, it is appropriate to visualize the entire system as composed of a number of groups, or subsystems, indicated by the dotted lines, with a limited number of connecting links between each group and its neighbors. It will be readily appreciated that, because of the restricted size of each individual group, a relatively small number of equations would be needed to describe its behavior, if it were disconnected from the rest of the system. It will be taken for granted that this smaller set of relations can be conveniently handled without difficulty. There remains to illustrate how the solutions of the several groups treated separately can be combined to describe the whole system.

Going to a somewhat simpler example, one may consider the case in Figure 2 (a) where only two

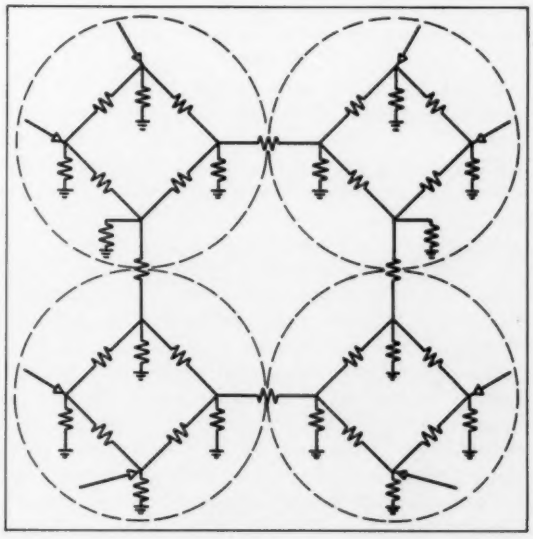

FIGURE 1

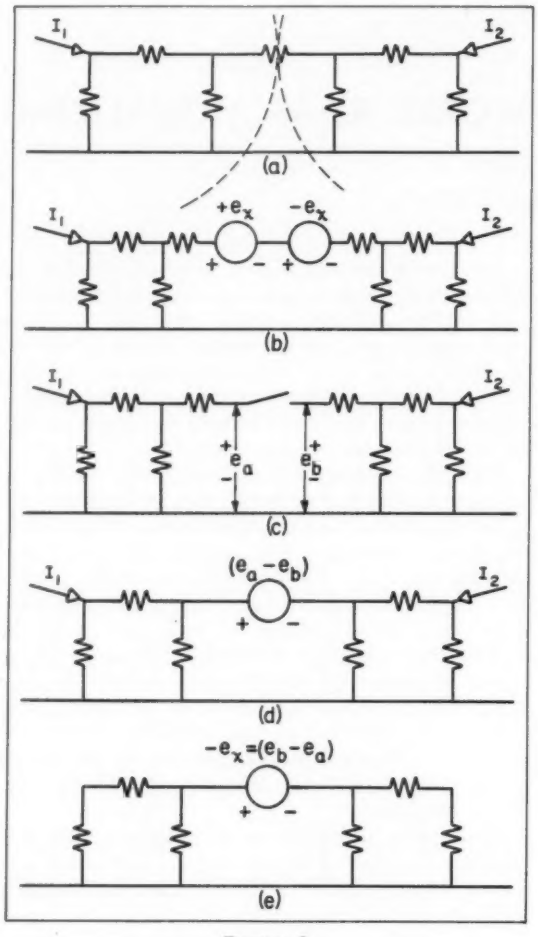

FIGURE 2

groups are involved, connected by a single link. The new system may alternately be represented as in Figure 2 (b), where the connecting link has been split into two parts, and two auxiliary voltage sources added. At the moment, these auxiliary sources are merely designated as e_x and $-e_x$. Since these two voltages are equal and opposite, they obviously do not disturb the remaining network values; their values could be chosen arbitrarily, but a particular choice will facilitate manipulation, as the following discussion will demonstrate.

Now let the same system be viewed with the connecting link opened, as in Figure 2 (c). The voltages e_a and e_b on the two sides of the switch are obviously determined by the sources in the separate parts. Since the two groups are separated, each voltage may evidently be determined independently without any consideration of the other. The system in Figure 2 (c) is now represented in still another way, as shown in Figure 2 (d), this time with a voltage generator inserted in the link, and having the specific voltage $(e_a - e_b)$. This is the special value desired for e_x. Note that such a voltage source does not contribute any current flow to the separated systems, since its value is chosen with this stipulation in mind

At this point, it is pertinent to return to consideration of Figure 2 (b), and to the implications contained in the problem involving the connected system. The system under consideration contains four sources, two real sources and two link sources. While the complete performance is determined by all sources acting together, the Superposition Principle, applicable to linear systems, implies that the several contributions may be obtained by adding the results obtainable from Figure 2 (c) or 2 (d), which take account of three sources, and the results obtainable from the system shown in Figure 2 (e), which contain the fourth source, $-e_x$, acting alone. A specific sequence of calculations is hereby indicated: first, the disconnected groups are to be solved separately to obtain information for determining the link voltage, $-e_x$; second, the link voltage is to be used to find a second set of values to be added to the first set.

What may not be immediately evident is that this final step may be subject to great simplification. Returning to the more extensive system of Figure 1, and applying the same general procedure, one arrives at the final step which involves a system containing a number of auxiliary sources, one inserted in each connecting link, and with no other sources operating. This permits each subsidiary group to be represented by a simplified equivalent system with respect to the

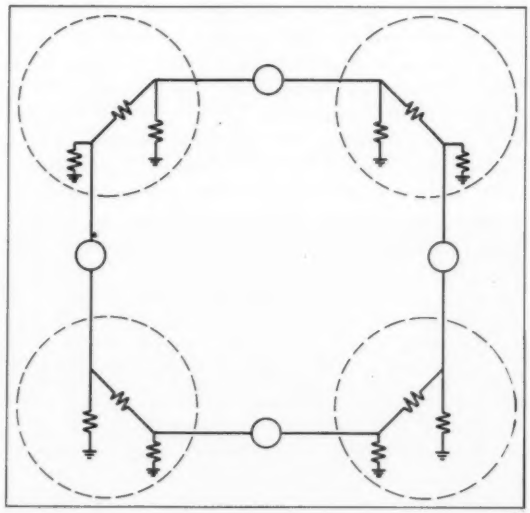

FIGURE 3

connecting point, as shown in Figure 3. Furthermore, these equivalents are derivable from consideration of the groups as separate entities, and, as previously indicated, these groups are assumed to be simple enough to permit their manipulation without difficulty.

It is pertinent to note that one needs to determine only the nodal voltages at the connecting points in Figure 3. These values added to the results of the "open link" calculations give the final voltages at the connecting points. A recalculation on an individual sub-group, using the sources within the group and the connecting node voltages as specified values, determines directly the final voltages everywhere within that sub-group.

Two final observations are appropriate concerning this procedure. It is fairly obvious that, when a sequence of studies are contemplated involving only modifications within one sub-group, then a relatively small amount of recalculation is required for new cases. Likewise one may observe that the number of sub-groups is subject to variation, so that a particular sub-group may be further divided into sub-sub-groups, if this is desirable. There is also no requirement that all the link source voltages be applied simultaneously; and they need not be, if there is an advantage in doing otherwise.

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ACKNOWLEDGMENT

The sponsorship by the city of Seattle Department of Lighting, of studies on digital computers, which led to this presentation, is gratefully acknowledged.

Lunar Tidal Variations in the Height of Ionospheric Layers

(Continued from page 13)

ACKNOWLEDGMENTS

The authors are indebted to the National Bureau of Standards for the loan of the ionospheric recorder and to Fred Mason of the Electrical Engineering Department for his technical assistance in its operation. The electronic digital computations have been supported by a grant from the Agnes H. Anderson Research Fund. The authors also thank the Radio Propagation Laboratory at Stanford University for the ionospheric data from Stanford, California.

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Engineering Research Dividends

DeGroot, E. B., "A Superheterodyne System for Cross-Modulation Measurements on Low-Power Traveling Wave Tubes." M.S. in Electrical Engineering, 1958.

An experimental technique is described for measuring the cross modulation in a 10-milliwatt 3000-megacycle traveling-wave tube. The technique is applied to a Huggins HA-1B tube to verify certain aspects of Putz's theoretical analysis of cross- modulation effects. The experimental results show considerable deviation from the behavior predicted in the theoretical analysis. It has not yet been determined whether the anomalous results are produced by the traveling-wave tube amplifier or by the measuring system itself.

Saugen, J. L., "A Study of Digitally Controlled Systems by Analog-Computer Simulation." M.S. in Electrical Engineering, 1958.

An analog-computer simulation of a control system containing a digital computer and its necessary conversion devices is reported in this thesis. The continuous part of the system is represented on the analog computer in the conventional manner; however, the collection of devices required to insert the digital computer into a system, called a digitroller, is simulated using relays and operational amplifiers. The simulation of the digital-computer program, a difference equation which can be represented by a rational polynomial in e^{-sT}, is achieved by the combination of sampling circuits and delay circuits. The simulation of a third-order program involves the use of twelve operational amplifiers.

Included are the results of studies of first- and second-order systems to which a digital computer has been added. Integration using Simpson's rule is also shown.

Otoshi, T. Y., "Investigation of the Cut-off Region for a Microwave Metal-Strip Artificial Dielectric." M.S. in Electrical Engineering, 1957.

The object of this investigation was to verify the existence of a cut-off region for the metal-strip artificial dielectric and to determine the accuracy in which the cut-off frequency can be predicted by available theories. Two theories were considered. The first theory by W. E. Kock predicted that cut-off

(Continued on page 36)

The New Engineer

(Continued from page 1)

between work, force, and distance which he must use under various circumstances and, if this continues, he may later wonder which relationship he must use for any given problem. Just as soon as the student has some calculus, he should be given the equation,

$$W = \int \mathbf{F} \cdot d\mathbf{s}$$

where the dot product is, of course, simply a mathematical shorthand for $F(\cos\theta)ds$. From this point on, *this equation should be used for all problems involving the energy produced by moving forces,* never the simpler form given first. The student will soon discover that, when he has a problem in which $\mathbf{F}$ is constant (not a function of $\mathbf{s}$) and $\cos\theta$ is constant and equal to unity (as often happens in some of the simpler applications), he can write $W = \int \mathbf{F} \cdot d\mathbf{s} = \int F\,(ds) = F \int ds = Fs$ and thus obtain the simpler form of the equation from the general. He no longer feels that there are several different forms of the work equation, from which he must select the proper one for the solution of his specific problem, but knows that there is only one fundamental form which may be used to solve all problems when properly applied.

The example given is probably too simple, and all will agree that the general approach should be used here as soon as the student has sufficient background in mathematics to understand it. Yet it is illustrative of the type of approach which is finding increasing use in engineering education today in an effort to free the thinking student from submersion in details and enable him to meet any problem with an increased chance of success, even if it is one he has never before encountered.

Where does the employer fit into this picture? Employers must realize, and indications are that a large number of them now do, that the graduating students are not practicing engineers but only potential engineers. The young graduate has most of the tools he needs to do engineering work but he has had very little chance to use them in solving real engineering problems. The problems and experiments he has worked as a college student represent only the barest minimum of experience needed to enable him to realize how his tools (engineering fundamentals) can be used, and the probability is that he has never attempted to solve a problem of the type presented by his employer. Left by himself he should be able to solve these problems in time, but much experience, some of it costly to his employer, must be gained before he learns the quickest and most economical way to approach the problems of his new job. A period of training and supervision under competent engineers, provided by his employer, will materially reduce the time and cost of developing the recent graduate into a full-fledged engineer, capable of cracking new frontiers with wide-open mind.

GRADUATE STUDIES AND RESEARCH IN ELECTRICAL ENGINEERING

(Continued from page 7)

A very detailed adverse report has been made on the Nez Perce project. The Wenatchee Project is under consideration now.

PROJECT: An engineering analysis of the power system of Anchorage, Alaska, and its environs.

SPONSORS: Cugach Electric Company and the City of Anchorage.

An engineering analysis was made of the power system and recommendations were submitted in the best interests of the people of Alaska.

W. E. ROGERS
Professor of Electrical Engineering
in cooperation with
J. C. FIREY
Associate Professor of Mechanical Engineering

PROJECT: A study of the velocities of acoustic waves in liquid-vapor mixtures.

SPONSOR: Engineering Experiment Station.

This study is directed toward learning more about condensation processes in general, and, specifically, about the flow of mixtures through orifices and pipes.

The first medium being investigated is wet steam at high pressures and temperatures. As is typical of this kind of investigation, the most difficult problem is to develop transducers which will operate in this environment, and at the same time will be capable of handling the extremely high power levels necessary to over-ride the noise generated by the moving vapors and by the equipment required to maintain a homogeneous mixture of liquid and vapor. At the present time, experiments are being carried on with a transducer formed of a thin plastic diaphragm which is acoustically coupled to a conventional dynamic speaker by a small resonant cavity. The cavity operates at the same pressure as the liquid-vapor mixture, but the gas serves to protect the electrical moving parts from the high temperatures.

GEORGE S. SMITH
Professor of Electrical Engineering

PROJECT: A study comparing electric heating with gas or oil for residential use.

For this study, two houses, each with its originally installed furnace, were each provided with sufficient electric panel heaters to heat them electrically. One house used in Yakima used its original modern type oil furnace, while the second in Seattle was originally provided with a coal furnace later converted to use city gas as the fuel for these tests.

The tests were started by using gas or oil one day and electric heat the next, but later the method of heating was changed weekly. Thus the tests compared the two methods of heating under similar weather conditions using the same house with the same family through the heating season.

The results of these tests will be reported in Sacramento, California, in August, 1958. Results are given in the form of heating factors and also in terms of cents cost per degree day per 1000 cubic feet at various fuel costs. The paper will also present material on the apparent operating efficiency of central furnaces. Another feature will be the variation of heating costs due to house construction, etc.

H. M. SWARM
Associate Professor of Electrical Engineering

Radio Propagation Laboratory. This Laboratory has three projects under study at the present time.

PROJECT: Ionospheric-Lunar Tidal Phenomena

This study has been assisted by a grant from the Agnes Anderson Research Fund for use of the IBM-650 Electronic Computer in calculating the height variation of ionospheric layers caused by the moon. Progress in this research is recorded in this issue of *The Trend in Engineering.*

PROJECT: Vertical Ionospheric Soundings

This project has on loan an automatic vertical ionospheric sounder from the National Bureau of Standards Radio Propagation Laboratory. Equipment has been operating since early January recording the virtual height of ionospheric layers as a function of frequency from 1 to 25 megacycles. Ionograms are recorded every fifteen minutes with this automatic equipment.

PROJECT: Satellite Radio Signal Recordings

Equipment is being assembled for automatic radio tracking and data processing of the telemetered signals from both American and foreign satellites.

Communication Theory Research. This group has two projects under investigation.

PROJECT: Information Content of Antennas

SPONSOR: Air Force Cambridge Research Center.

This project is concerned with the study and application of information theory to antenna synthesis criteria.

PROJECT: Information Theory Applications to Language Translation

This project is co-supervised by Dr. D. L. Johnson and is closely related to the Mechanical Language Translation Project. The study is concerned with the application of information theory techniques to the measure of the degree of language translation and to the logical processing of rules for language translation.

A Broadband Dual-Mode Transducer

(Continued from page 30)

crystal detector that was used for measuring the relative incident power. The calibrated attenuator was set so that the indicated power level was identical to the previous relative incident power level. The coupled power P in decibels below the incident power was determined by the relation,

$$P = C - (\text{Final calibrated attenuator setting} + 3 \text{ db}).$$

The value C in the above relation is the number of decibels of coupling of the directional coupler. Since this value deviated slightly from 20 db with frequency, it was necessary to calibrate the directional coupler to determine the exact value of C at each desired frequency. The by-passed, or uncoupled, power was measured in the same manner except that the matched detector was applied at the output of the TE_{20} mode feed guide instead of at the output of the two-mode guide. The cross coupling was measured at each frequency in the following manner. A matched crystal detector was connected to the TE_{20} mode feed arm of the transducer. The TE_{10} mode feed arm was matched for minimum input VSWR by an impedance transformer. With the attenuator set to zero, the detector reading was observed when power was fed into the matched TE_{10} mode feed arm. The attenuator was then adjusted so that the detector reading was the same as the previous reading with the TE_{10} mode feed arm replaced by the detector.

Applications

Although the intended function of the dual-mode transducer was to provide the required excitation for experimental antennas, several other uses are suggested.

1. The transducer may be used with a ferrite phase shifter and waveguide tee to form a fast-acting electronically controlled waveguide switch.[9]
2. The TE_{20} mode output of the transducer could serve as broadband exciter for the TE_{01n} modes used in dielectrometer cavities.[11]
3. By removing the TE_{10} mode tapered feed and decreasing the coupling to the TE_{20} mode, the directivity of the transducer would be increased sufficiently so that it could be used with a ratio to determine reflection coefficients in a TE_{20} waveguide.

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CUT-OFF REGION FOR A MICROWAVE ARTIFICIAL DIELECTRIC

(Continued from page 34)

would appear in the form of anomalous dispersion at the strip resonant frequency dependent upon strip width. The second theory by S. B. Cohn predicted that energy cut-off would occur in the form of a filter stop band at a frequency dependent upon the physical dimensions and spacings of the strip elements.

Existence of cut-off regions was found experimentally for two different designs of metal-strip artificial dielectric. For both designs, the cut-off characteristics behaved in the manner of a filter stop band. In the case of one design, the experimental cut-off frequency occurred near the cut-off frequency predicted by Cohn's theory, but agreed poorly with the cut-off frequency predicted by Kock's theory. In the case of the second design, the experimental cut-off frequency showed poor agreement with the predicted cut-off frequencies of both Kock's and Cohn's theories. The experimental results are presented and reasons for disagreement between theoretical and experimental results are discussed.

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